

11-18  
025747

# SAMS Acceleration Measurements on Mir From November 1995 to March 1996

Richard DeLombard  
*Lewis Research Center*  
*Cleveland, Ohio*

April 1997



National Aeronautics and  
Space Administration



# **SAMS Acceleration Measurements on Mir from November 1995 to March 1996**

March 14, 1997

Richard DeLombard  
NASA Lewis Research Center  
Cleveland, Ohio



## **Abstract**

The NASA Microgravity Science and Applications Division (MSAD) sponsors science experiments on a variety of microgravity carriers, including Orbiter missions and Russia's Mir space station. The MSAD sponsors the Space Acceleration Measurement System (SAMS) at the NASA Lewis Research Center (LeRC) to support these science experiments by providing acceleration measurements to characterize the microgravity environment to which the experiments were exposed. The LeRC Principal Investigator Microgravity Services (PIMS) project supports principal investigators of microgravity science experiments as they evaluate the effects of varying acceleration levels on their experiments.

In 1994, a SAMS unit was installed on the Mir space station. In a manner similar to Orbiter mission support, the SAMS unit supports science experiments from the U.S. and Russia by measuring the microgravity environment during experiment operations. Previous reports have summarized the SAMS data acquired during the period from September 1994 to November 1995.

During the time period from November 1995 to March 1996, the primary SAMS-supported experiment was a Protein Crystal Growth (PCG) experiment. SAMS data were obtained during the PCG operations on Mir in accordance with the requirements specified by the PCG Principal Investigator. Also included in this data are mission events of interest, such as the undocking of STS-74 from Mir (November 1995) and the docking of Atlantis (STS-76) to Mir in March 1996. This report presents an overview of the SAMS data recorded in the interval from November 1995 to March 1996.

**Acronyms and Abbreviations**

|      |                                                |
|------|------------------------------------------------|
| DMT  | Decreed Moscow Time                            |
| Hz   | Hertz                                          |
| LeRC | NASA Lewis Research Center                     |
| MSAD | Microgravity Science and Applications Division |
| PCG  | Protein Crystal Growth experiment              |
| PCSA | principal component spectral analysis          |
| PIMS | Principal Investigator Microgravity Services   |
| PSD  | power spectral density                         |
| RMS  | root mean square                               |
| SAMS | Space Acceleration Measurement System          |
| TSH  | triaxial sensor head                           |
| WWW  | world wide web                                 |

## Table of Contents

|                                                                   |        |
|-------------------------------------------------------------------|--------|
| Abstract .....                                                    | i      |
| Abbreviations and Acronyms .....                                  | ii     |
| Table of Contents .....                                           | iii    |
| List of Tables / List of Figures / Acknowledgments .....          | iv     |
| 1. Introduction and Purpose .....                                 | 1      |
| 2. Data Acquisition and Processing .....                          | 1      |
| 3. Mission Configuration .....                                    | 2      |
| 3.1 Mir Configuration .....                                       | 2      |
| 3.2 Mir Coordinate System .....                                   | 2      |
| 3.3 Mir Attitudes .....                                           | 2      |
| 4. Triaxial Sensor Head Orientation and Location .....            | 3      |
| 5. Protein Crystal Growth Experiment Location .....               | 3      |
| 6. Mission Activities .....                                       | 3      |
| 7. Analysis Techniques .....                                      | 3      |
| 8. Shuttle - Mir undocking and docking events .....               | 4      |
| 9. Russian Vehicle Docking .....                                  | 5      |
| 10. Microgravity Environment .....                                | 5      |
| 10.1 Gyrodynes .....                                              | 5      |
| 10.2 Crew Exercise .....                                          | 6      |
| 11. Summary .....                                                 | 6      |
| 12. References .....                                              | 7      |
| <br>APPENDIX A Accessing Acceleration Data Via the Internet ..... | <br>A1 |
| APPENDIX B SAMS 100 Hz sensor head data plots .....               | B1     |
| APPENDIX C SAMS 10 Hz sensor head data plots .....                | C1     |
| APPENDIX D User Comment Sheet .....                               | D1     |

## **List of Tables**

|          |                                              |   |
|----------|----------------------------------------------|---|
| Table 1. | SAMS TSH Orientation in Kvant-1 module ..... | 8 |
|----------|----------------------------------------------|---|

## **List of Figures**

|          |                                                                               |    |
|----------|-------------------------------------------------------------------------------|----|
| Figure 1 | Recorded data times with major mission events identified.....                 | 9  |
| Figure 2 | Typical configuration of the Mir space station.....                           | 10 |
| Figure 3 | Color plot of the first STS-76-Mir data.....                                  | 11 |
| Figure 4 | PSD of the Mir microgravity environment before the Orbiter docked to Mir..... | 12 |
| Figure 5 | PSD of the Mir microgravity environment after the Orbiter docked to Mir.....  | 13 |

## **Acknowledgments**

Milton Moskowitz provided SAMS data analysis for this report.



## 1. Introduction and Purpose

The NASA Microgravity Science and Applications Division (MSAD) sponsors science experiments on a variety of microgravity carriers, including Orbiter missions and Russia's Mir space station. The MSAD sponsors the Space Acceleration Measurement System (SAMS) at the NASA Lewis Research Center (LeRC) to support these science experiments by providing acceleration measurements to characterize the microgravity environment to which the experiments were exposed. The LeRC Principal Investigator Microgravity Services (PIMS) project supports principal investigators of microgravity science experiments as they evaluate the effects of varying acceleration levels on their experiments.

In 1994, a SAMS unit [1] was installed on the Mir space station. In a manner similar to Orbiter mission support, the SAMS unit supports science experiments from the U.S. and Russia by measuring the microgravity environment during experiment operations. Previous reports [2-4] have summarized the SAMS data acquired during the period from September 1994 to November 1995.

During the time period from November 1995 to March 1996, the primary SAMS-supported experiment was a Protein Crystal Growth (PCG) experiment. SAMS data were obtained during the PCG operations on Mir in accordance with the requirements specified by the PCG Principal Investigator. Also included in this data are mission events of interest, such as the undocking of STS-74 from Mir (November 1995) and the docking of Atlantis (STS-76) to Mir in March 1996. This report presents an overview of the SAMS data recorded in the interval from November 1995 to March 1996.

Appendix A describes the procedures to access additional information about SAMS and PIMS utilizing the internet. Appendix B provide plots of the SAMS 100 Hz sensor head data and Appendix C provide plots of the SAMS 10 Hz sensor head data as an overview of the microgravity environment. Appendix D contains a user comment sheet. Users are encouraged to complete this form and return it to the authors.

## 2. Data Acquisition and Processing

As reported earlier [2-4], the SAMS unit on Mir has two triaxial sensor heads (TSH) with cutoff frequencies of 100 Hz (TSH A) and 10 Hz (TSH B).

The SAMS unit recorded microgravity acceleration periodically to support the characterization of the microgravity environment for the PCG experiment. Eleven SAMS data disks were returned to Earth on STS-76 after its rendezvous mission in March 1996. These data were processed by the SAMS project and made available to users on a NASA LeRC file server. See Appendix A for instructions on accessing these data. The data coverage for this time period is shown graphically in figure 1. It should be noted that data during days 84 and 85 of 1996 is not valid for TSH A due to an unknown problem on Mir. It appears from the data recorded on the flight disks as if the sensor head was not connected properly during days 84 and 85.

The SAMS data from Mir were examined by PIMS to determine characteristics of the data to support PCG and to further characterize the Mir microgravity environment. The prior reports [2-4] summarize the characteristics of the SAMS data from previous SAMS operations on Mir.

### **3. Mission Configuration**

#### **3.1 Mir Configuration**

The Mir space station was launched in 1984 as a base module and has been expanded since that time to include five modules in early 1996. Figure 2 shows a typical configuration of the Mir space station during the time covered by this report. The five major components are the Mir core module, the Kvant astrophysics module, the Kvant-2 scientific and airlock module, the Kristall technological module, and the Spektr laboratory module. The Mir modules are occasionally reoriented for mission activities such as vehicle docking events.

The Priroda module was added in April 1996. The overall space complex mass exceeds 90,700 kilograms. The length along the longitudinal axis is about 33 meters and the length along the lateral axis is about 27 meters.

#### **3.2 Mir Coordinate System**

The Mir basic coordinate system is the base module coordinate system shown in Figure 2.

#### **3.3 Mir Attitudes**

The orientation attitudes of Mir during the November 1995 to March 1996 time period are not known at the present time.

The Mir space station periodically corrects its attitude. This is accomplished by turning station-keeping gyrodynes off, and using thrusters to establish the desired attitude. When the new attitude is established, the gyrodynes are turned on again. The exact meaning of gyrodyne "turn off" is not clear, but it is believed that it refers to disengaging a clutch mechanism and does not mean stopping the gyrodyne rotation.

#### **4. Triaxial Sensor Head Orientation and Location**

The SAMS TSHs are mounted to a structure or an experiment in a predetermined manner. The orientation of the TSH axes relative to the vehicle is measured and recorded for later use in understanding the acceleration data. Using this information, the measured acceleration levels may be transformed to other orientations, such as an experiment-based coordinate system or the Mir coordinate system. The data is presented in the SAMS coordinate system for this report.

A PCG Dewar apparatus was installed on Mir in November 1995 during the STS-74 mission. During the time frame of this report, the SAMS TSHs were mounted near the PCG apparatus in the Kvant module. Table 1 lists the location and orientation of the two active TSHs during these operations. The SAMS sensors were mounted in the Kristall module during the STS-74 Shuttle undocking.

#### **5. Protein Crystal Growth Experiment Location**

The PCG apparatus was located in the Kvant module. The exact location and orientation are not known at the present time.

#### **6. Mission Activities**

Science activity summaries and NASA press releases have been examined for major activities during this time period. These sources of information do not give any detail concerning the operation of Mir equipment which may cause disturbances to the microgravity environment. Known activities which may have caused disturbances during the span of SAMS recorded data are listed and/or described below. Major activities occurring on Mir are summarized in figure 1 along with a graphical view of the SAMS data recording and the typical daily cycle of the crew. As reported earlier [4], the normal awake period for the Mir crew is reported to be from 08:00 until 23:00. Exercise is conducted on a daily basis and the crew members have three meals per day.

The times shown are in hour/minute:second format and are based on Decreed Moscow Time (DMT).

#### **7. Analysis Techniques**

The SAMS data were examined using acceleration versus time, power spectral density (PSD) vs. frequency, and spectrogram (PSD vs. frequency vs. time) techniques. Each of these techniques highlight different factors contained in the data.

The PSD calculations are typically used to examine the frequency content of short periods of data on the order of minutes. The PSD techniques used by PIMS are described in [5].

The spectrograms are used to show how the microgravity environment varies in intensity with respect to both the time and frequency domains. The spectrogram technique is explained in [5]. The spectrograms serve as a roadmap to the data for interpreting the activities which occurred.

## 8. Shuttle - MIR undocking and docking events

A previous report of SAMS data from Mir [4] included the docking of STS-74 to Mir and the initial operations of that joint mission. The SAMS data disks contained in that report were returned on STS-74 when it undocked at 08:13 GMT on 18 November 1995.

The data described in the present report begins during the joint STS-74 - Mir mission and includes the undocking of STS-74. The undocking occurred on GMT day 322 and was complete at 322/11:15:44 GMT. The undocking procedure is similar to the docking, but with the sequence of steps being performed in reverse. Therefore, first the latches are unhooked, thus breaking the hard-mate, and then the soft-mate is broken. The shuttle then slowly backs away from Mir, using the Vernier Reaction Control System jets, so as not to disturb Mir's solar arrays.

After the hard-mate is broken, the structural modes of the shuttle-Mir complex begin to revert back to the structural mode of Mir alone. Changes in the structural modes may be seen in Figure 3. Notice the broad-band disturbance (thin vertical magenta and yellow line) around DMT 322/11:16 in the plot. This is the apparent hard-mate separation. Comparison of the microgravity environment before and after this event show that some structural modes shift (the 4.5 Hz shifts back down to 4 Hz), while some disappear entirely (i.e. the 2.5 Hz mode).

In addition to these changes in the structural (i.e. lower frequency) modes, higher frequency accelerations which were generated on the shuttle disappear from the recorded Mir environment. Figure 4 shows a spectrogram of the same time period out to 25 Hz. Notice that at the time of undocking, there is an abrupt disappearance of the 17 Hz and 23 Hz signals (the orbiters Ku-antenna dither, and a disturbance from an unknown source aboard Atlantis). Additionally, the periodic 22 Hz signal, caused by the Enhanced Orbiter Refrigerator Freezer (EORF) located in the Orbiters SPACEHAB module, ceases at that time.

The docking of Atlantis (STS-76) to Mir was initiated at DMT 05:34 a.m. on 24 March 1996 [7, 8]. Docking was complete at DMT 05:50 a.m. on 24 March 1996. Docking occurred between the Orbiter Docking System in the forward area of Atlantis' payload bay and the Docking Module installed during STS-74 on Mir's Kristall module docking port.

The most noticeable differences between the spectrogram plots before and after the Orbiter docked to Mir are the 17 Hz peak from the Ku-band antenna and magnitude changes in frequencies less than 10 Hz (due to structural mode differences).

The difference between the time cited for the Shuttle-Mir docking and the apparent time of the docking is attributed to inaccuracies in recording the power-on time of the SAMS unit on-board Mir prior to the docking. Because the Mir Integration Payload System (MIPS) time synchronization signal was not available at power-up time, the SAMS data time assignment was performed using crew notations as a reference. This anomaly is being investigated.

## 9. Russian Vehicle Docking

The Mir 21 mission began when the crew launched on February 21, 1996, in a Soyuz vehicle and docked with the Mir two days later.

## 10. Microgravity Environment

### 10.1 Gyrodynes

The Mir station uses gyrodynes in order to maintain attitude control. Each module contains at least one group of six gyrodynes. While performing attitude changes, it is believed that the gyrodynes are de-coupled, thus permitting thruster jets to re-orient the station to the desired attitude. However, at times, the gyrodynes are spun-down (i.e. brought to a halt), or spun-up (i.e. restarted). The nominal rotational rate for the gyrodynes is 10,000 revolutions per minute, which translates to a frequency of approximately 166 Hz.

The SAMS sensor head on Mir with the highest frequency response has a cutoff frequency of 100 Hz with the data being sampled at 500 samples per second. This results in the Nyquist frequency being 250 Hz for this sampled data set. Therefore, that SAMS sensor head records acceleration data with frequency content up to 250 Hz, although all information above 100 Hz has been attenuated by the lowpass filter.

Figure 5 shows a spectrogram from DMT 340/16 - 340/22 (year 1995), showing two gyrodyne spin-up periods. The first begins at roughly DMT 340/16:15, and multiple frequency traces may be seen, extending to the final (nominal gyrodyne speed) frequency of 166 Hz. The second group of gyrodynes began their spin-up around DMT 340/19:20, and increases upwards towards 166 Hz (166 Hz is reached around DMT 340/21:45).

The NASA Johnson Space Center Payload Operations Support Area report from that date (6 Dec 95) indicates that the three gyrodynes in Kvant, and the two gyrodynes in Kvant-2 were to be spun-up on that day. During that time period, the SAMS unit was located in the Kvant module. It is believed that the SAMS data shows the spin-up of two of the three gyrodynes in the Kvant module. It is further believed that the "spin-up of one gyrodyne" is actually the spin-up of the six gyrodynes in the gyrodyne bank, thus causing the multiple (nearly overlapping) frequency traces to be observed. A similar event for a gyrodyne spin-down is seen in the SAMS data from DMT 249/17:00 and reported in [4]. The spin-down action lasted more than three hours from start to finish.

## 10.2 Crew exercise

Disturbances from crew exercise are apparent in this data as it was in earlier SAMS data [2-4].

## 11. Summary

This report presents an examination of the SAMS data acquired on the Mir space station from November 1995 to March 1996.

The SAMS unit on-board Mir was installed to support the U.S. PCG experiment flown on Mir under the Shuttle-Mir Science Program (SMSP). The SAMS TSHs were mounted near the PCG apparatus and recorded data during the times specified by the PCG PI.

A summary of the vector magnitude RMS and average accelerations for the entire data set was produced for the SAMS 100 Hz TSH. Spectrograms were also produced to give a frequency domain summary for the entire mission. These plots are presented in appendix B. Some characteristics of the SAMS data are outlined in relation to known activities occurring on Mir at times for which data were recorded.

Future work will continue in order to correlate activities and operations with the microgravity environment, and to compare the Mir microgravity environment with that of the NASA Orbiters. As additional data is acquired from SAMS operations on Mir, further analyses will be performed.

## 12. References

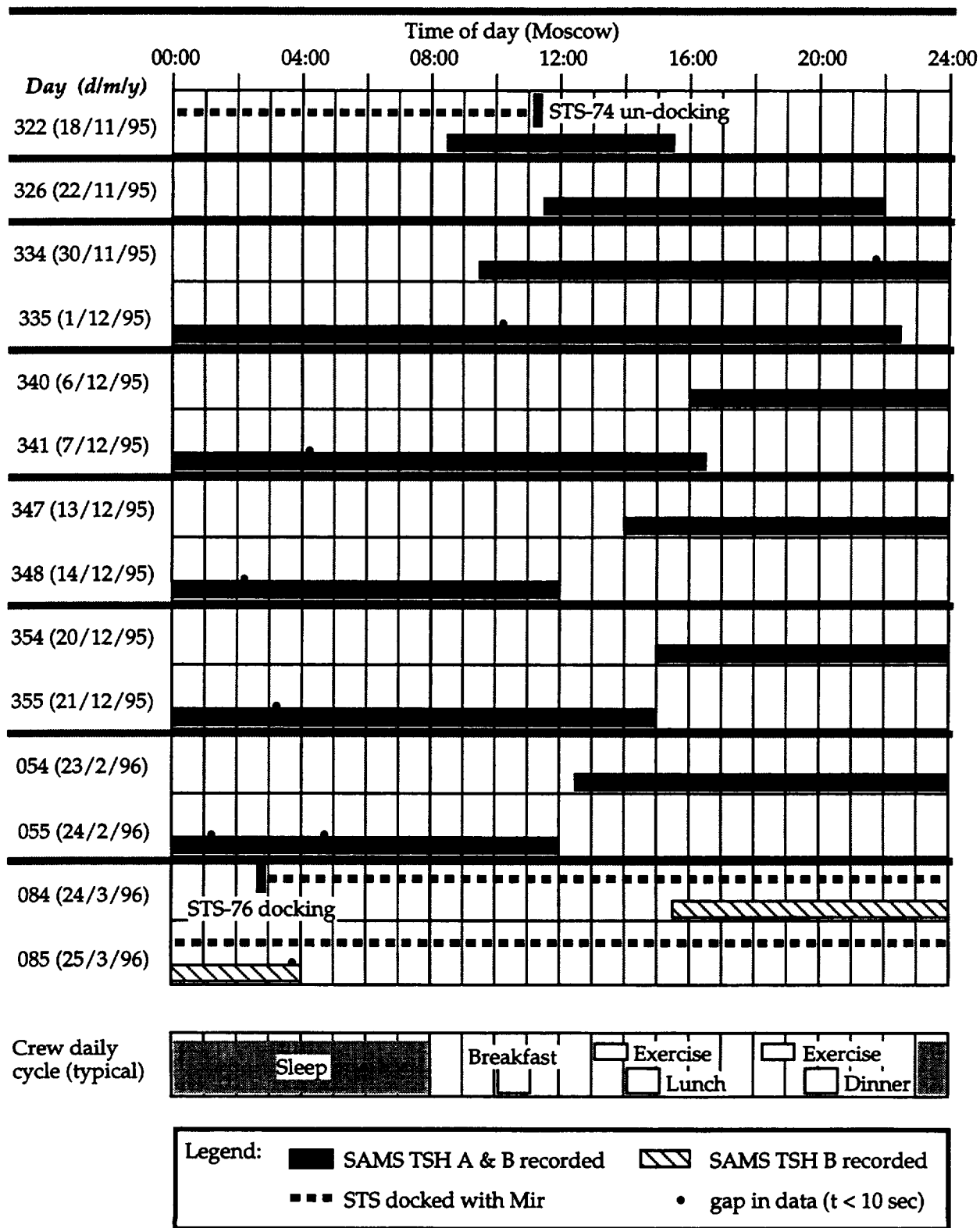
- [1] DeLombard, R. and Finley, B.D. (Sverdrup Technology, Inc.): Space Acceleration Measurement System Description and Operation on the First Spacelab Life Sciences Mission, NASA TM-105301, 1991.
- [2] DeLombard, R. and M. J. B. Rogers: Quick Look Report of Acceleration Measurements on Mir Space Station during Mir-16. NASA TM-106835, 1995.
- [3] DeLombard, R., S. B. Ryaboukha, M. Moskowitz, K. Hrovat: Further Analysis of the Microgravity Environment on Mir Space Station during Mir-16. NASA TM-107239, June 1996.
- [4] DeLombard, R., K. Hrovat, M. Moskowitz, and K. McPherson: SAMS Acceleration Measurements on Mir From June to November 1995. NASA TM-107312, September 1996
- [5] DeLombard, R.: Compendium of Information for Interpreting the Microgravity Environment of the Orbiter Spacecraft. NASA TM-107032, August 1996
- [6] Granier, J.-P., P. Faucher, S. Ryaboukha: Mir Microgravity Environment, "microaccelerometre" Experiment. 24th International Conference on Environmental Systems, Friedrichshafen, Germany, June 20-23, 1994.
- [7] STS-76 Day 3 Highlights electronic report (March 24, 1996) on the World Wide Web at Uniform Resource Locator: <http://www.ksc.nasa.gov/shuttle/missions/sts-76/sts-76-day-03-highlights.html>
- [8] Telephone conversation with Brenda Eliason/NASA JSC about Shuttle-Mir docking times
- [9] WWW URL: <http://www.osf.hq.nasa.gov/> on 3/29/96

| TSH | Location  | TSH Axis | Mir Axis |
|-----|-----------|----------|----------|
| A   | Panel 210 | $X_h$    | $X_b$    |
|     |           | $Y_h$    | $-Y_b$   |
|     |           | $Z_h$    | $-Z_b$   |
| B   | Panel 414 | $X_h$    | $X_b$    |
|     |           | $Y_h$    | $Y_b$    |
|     |           | $Z_h$    | $Z_b$    |

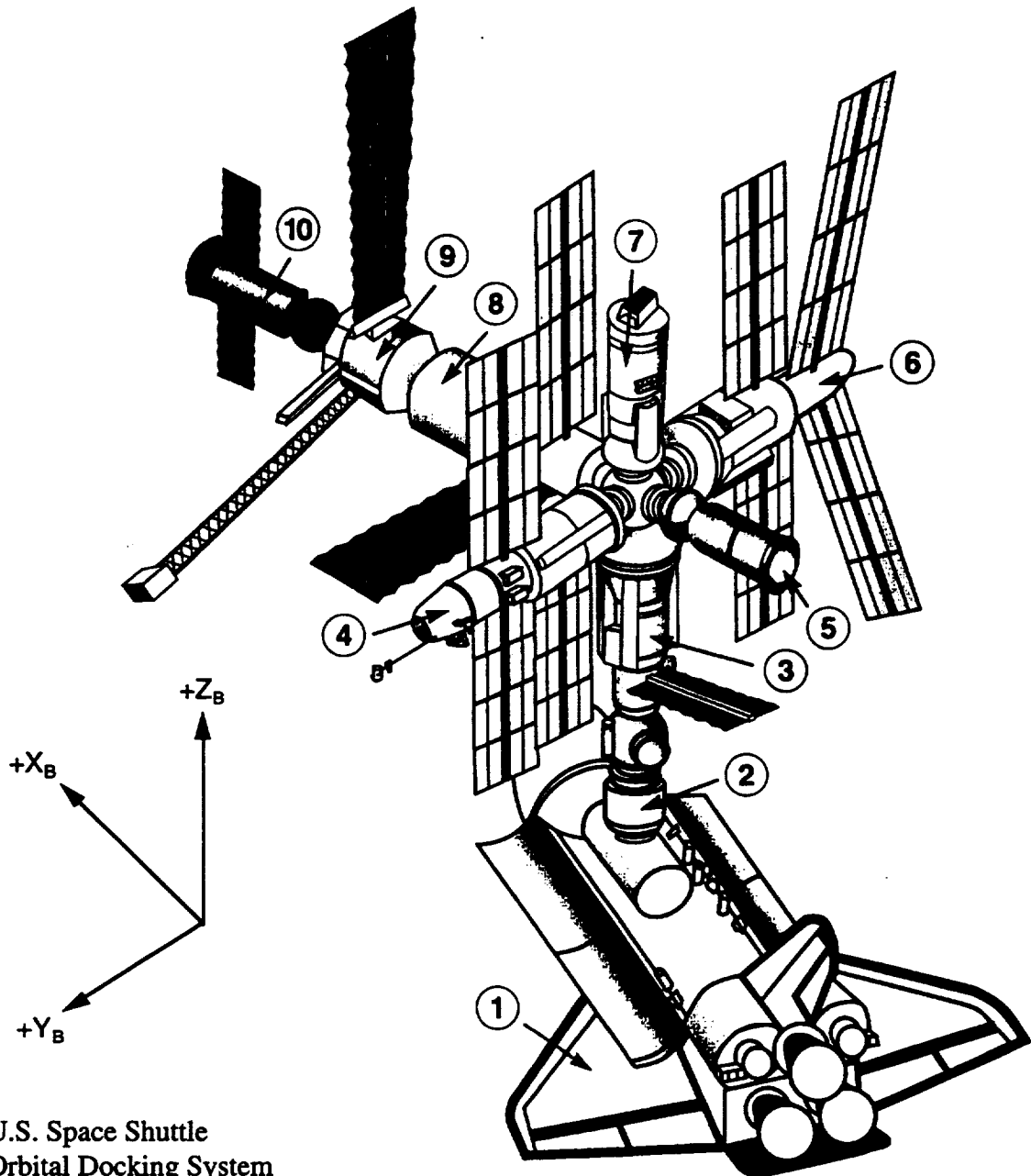
**Table 1.** SAMS TSH Orientation in Kvant-1 module.



# SAMS ACCELERATION MEASUREMENTS ON MIR FROM NOVEMBER 1995 TO MARCH 1996



**Figure 1.** Recorded data times with major mission events identified.



- 1) U.S. Space Shuttle
- 2) Orbital Docking System
- 3) Kristall module: materials processing
- 4) Kvant II module: logistics
- 5) Soyuz transport vehicle
- 6) Spektr module: geophysical sciences
- 7) Priroda module: U.S. facilities, Earth Observation
- 8) Core module: habitation, power, life support
- 9) Kvant module: astrophysics
- 10) Progress vehicle

**Figure 2.** Typical configuration of the Mir space station.

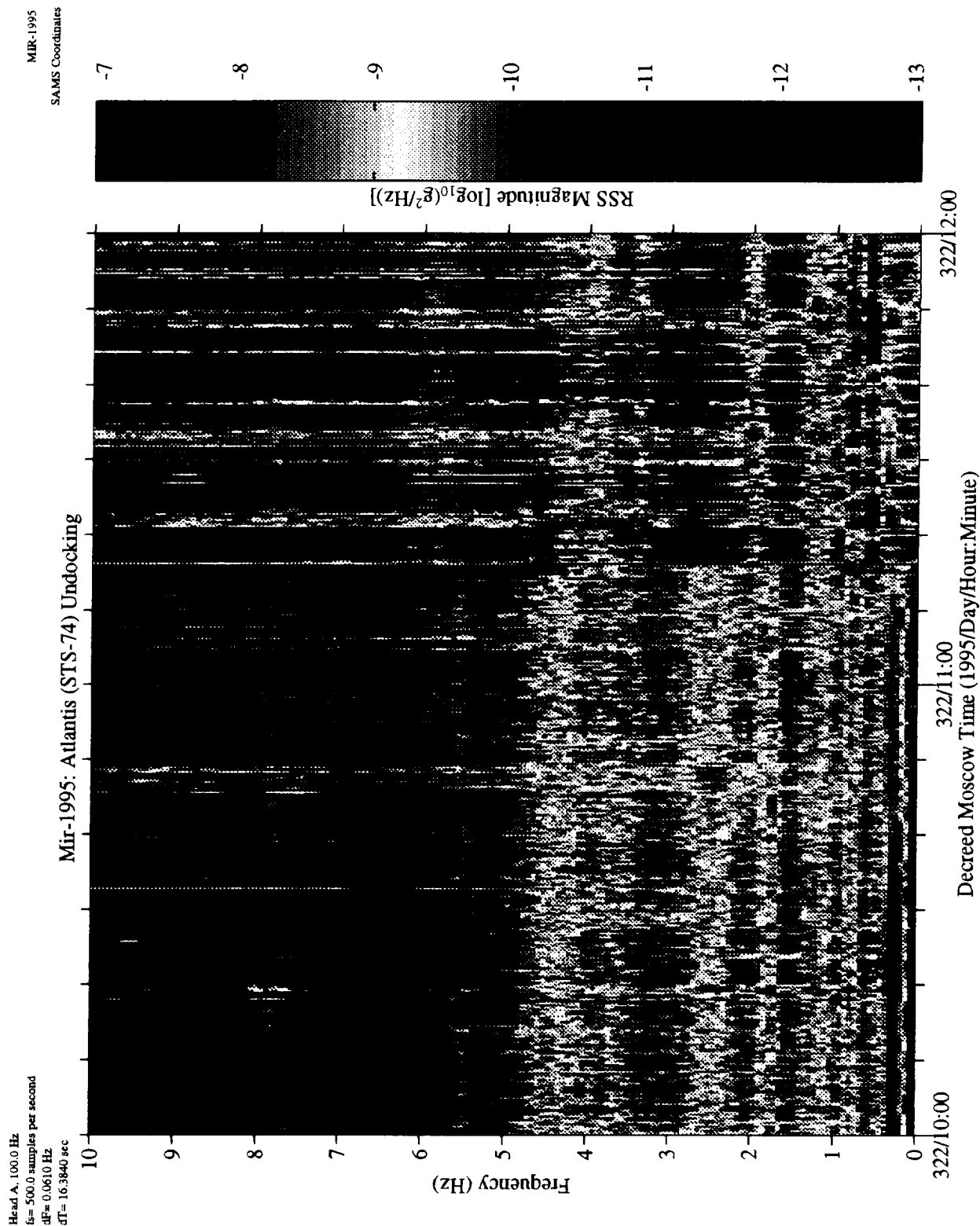


Figure 3. Color plot of the first STS-76-Mir data

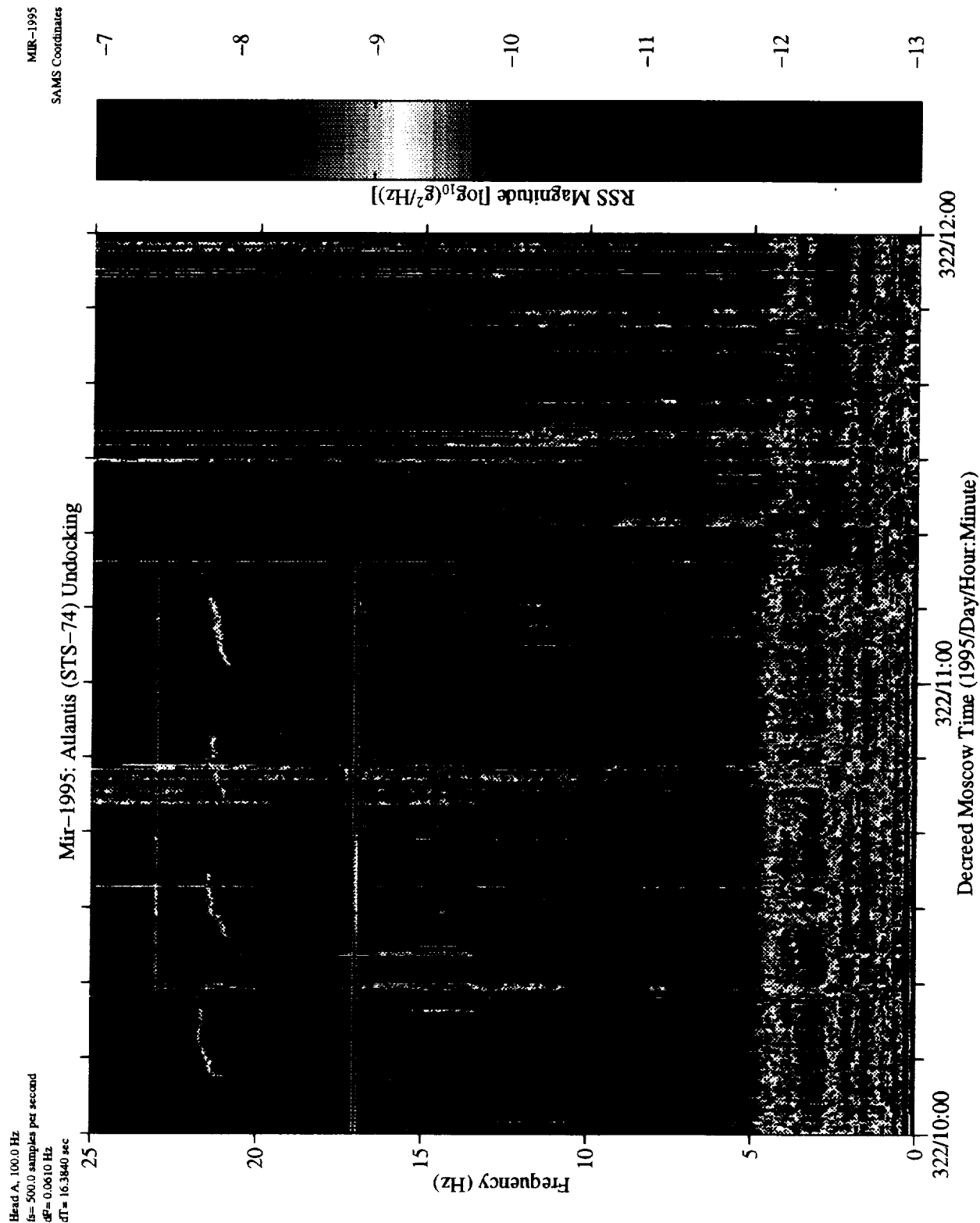


Figure 4. PSD of the Mir Microgravity environment before the Orbiter docked to Mir

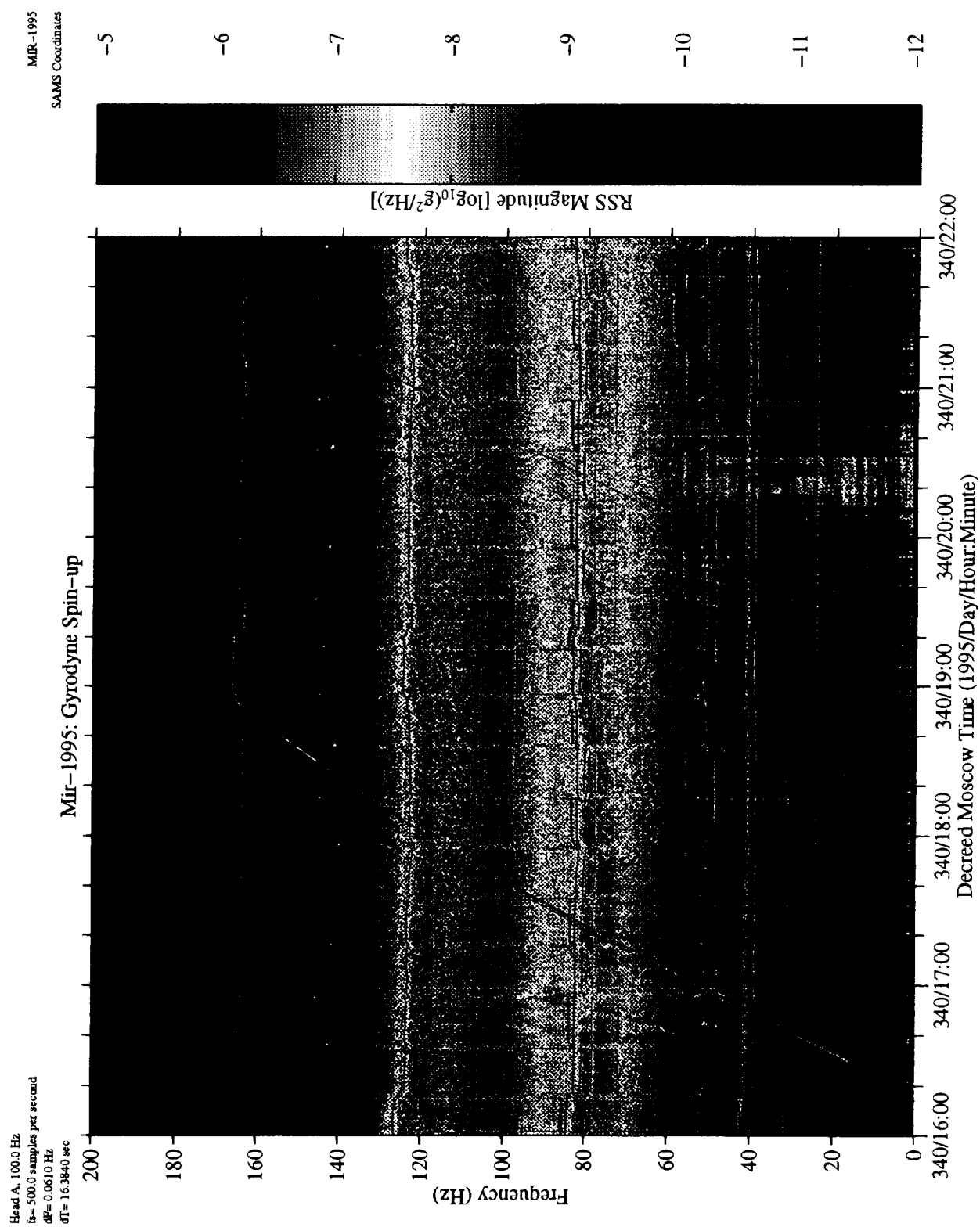


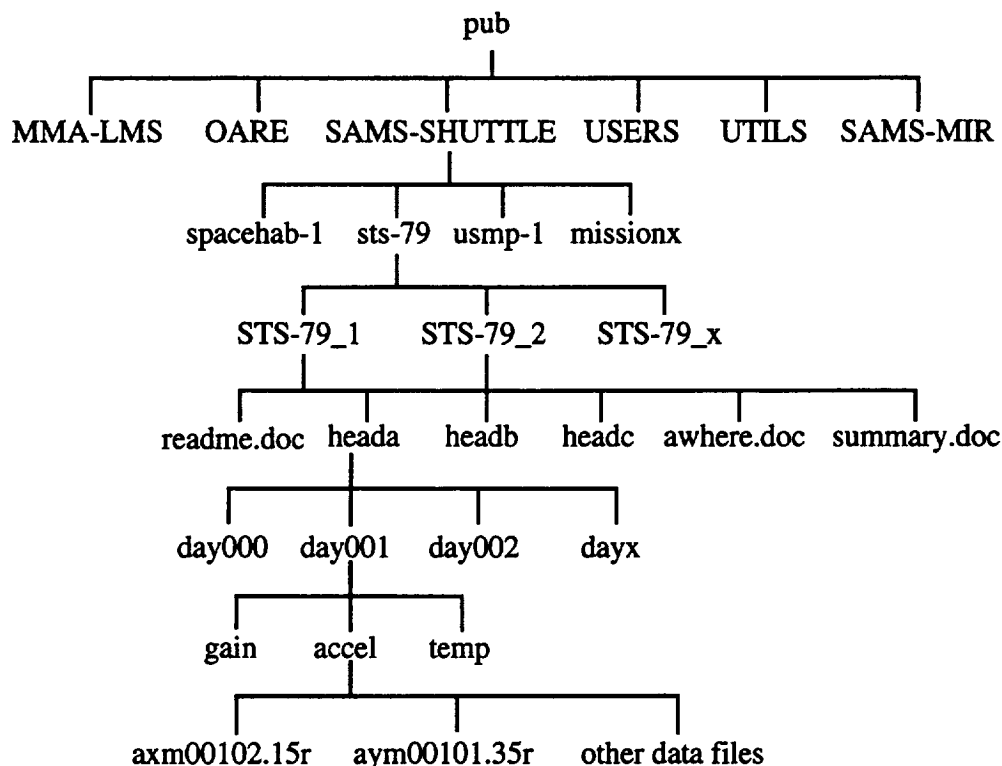
Figure 5. PSD of the Mir Microgravity environment after the Orbiter docked to Mir



## Appendix A: Accessing Acceleration Data via the Internet

SAMS and OARE data are available over the internet from the NASA LeRC file server "beech.lerc.nasa.gov". Previously, SAMS data were made available on CD-ROM, but distribution of data from current (and future) missions will be primarily through this internet file server.

SAMS data files are arranged in a standard tree-like structure. Data are first separated based upon mission. Then, data are further subdivided based upon some portion of the mission, head, year (if applicable), day, and finally type of data file (acceleration, temperature, or gain). Effective November 1, 1996, there has been a minor reorganization of the beech.lerc.nasa.gov file server. There are now two locations for SAMS data: a directory called SAMS-SHUTTLE and a directory called SAMS-MIR. Under the SAMS-SHUTTLE directory, the data are segregated by mission. Under the SAMS-MIR directory, the data are segregated by year. The following figure illustrates this structure.



The SAMS data files (located at the bottom of the tree structure) are named based upon the contents of the file. For example, a file named "axm00102.15r" would contain head A data for the x-axis for day 001, hour 02, file 1 of 5. The readme.doc files give a complete explanation of the file naming convention.

Data access tools for different computer platforms (MS-DOS, Macintosh, SunOS, and MS-Windows) are available in the /pub/UTILS directory.

The NASA LeRC beech file server can be accessed via anonymous File Transfer Protocol (ftp), as follows:

- 1) Open an ftp connection to "beech.lerc.nasa.gov"
- 2) Login as userid "anonymous"
- 3) Enter your e-mail address as the password
- 4) Change directory to pub
- 5) List the files and directories in the pub directory
- 6) Change directories to the area of interest
- 7) Change directories to the mission of interest
- 8) Enable binary file transfers
- 9) Use the data file structures (described above) to locate the desired files
- 10) Transfer the desired files

If you encounter difficulty in accessing the data using the file server, please send an electronic mail message to "pims@lerc.nasa.gov". Please describe the nature of the difficulty and also give a description of the hardware and software you are using to access the file server. If you are interested in requesting specific data analysis or information from the PIMS team, also send e-mail to pims@lerc.nasa.gov or call the PIMS Project Manager, Duc Truong at (216) 433-8394.



## Appendix B: SAMS Time Histories and Color Spectrograms TSH A

The Principal Investigator Microgravity Services (PIMS) group has further processed SAMS data to produce the plots shown here. Three representations of the data are presented here: ten second interval average, ten second interval RMS, and PSD magnitude versus frequency versus time (spectrogram) plots. These calculations are presented in 8 hour plots, with the corresponding average and RMS plots on one page, and the spectrogram on the facing page.

The ten-second interval average plots give an indication of net accelerations which last for a period of 10 seconds or more. Shorter duration, high amplitude accelerations may be seen with this type of plot, however their exact timing and magnitude cannot be extracted. The ten-second interval RMS plots give a measure of the oscillatory content in the acceleration data. Plots of this type may be used to identify times when oscillatory and/or transient deviations from the background acceleration levels occurred.

Color spectrograms are used to show how the microgravity environment varies in intensity with respect to both the time and frequency domains. These spectrograms are provided as an overview of the frequency characteristics of the SAMS data. Each spectrogram is a composite of 8 hour's worth of data. The time resolution used to compute the spectrograms seen here is 16.384 seconds. This corresponds to a frequency resolution of 0.0610 Hz.

These data were collected at 500 samples per second, and a 100 Hz low pass filter was applied to the data by the SAMS unit prior to digitization. Prior to plot production, the raw SAMS data were compensated for gain changes, and then demeaned. Demeaning was accomplished by analyzing individual sections with a nominal length of 12 minutes. Users who are interested in further details for either of these operations are encouraged to contact the PIMS group.

### Interval Average and Root Mean Square Calculations

The interval average plots were produced by calculating the average of ten second intervals of data for each axis. This operation is described as:

$$x_{avg_k} = \frac{1}{M} \sum_{i=1}^M x_{(k-1)M+i},$$

where  $x$  represents the  $x$ ,  $y$ , or  $z$  axis data,  $M$  is the number of points analyzed in an interval, and  $k$  refers to the  $k$ th interval analyzed.

The resulting data streams ( $x_{avg_k}$ ,  $y_{avg_k}$ ,  $z_{avg_k}$ ) are then combined by a vector-magnitude operation.

This computation is expressed mathematically as:  $accel_{avg_k} = \sqrt{x_{avg_k}^2 + y_{avg_k}^2 + z_{avg_k}^2}$ .

The interval RMS plots were produced by taking the root-mean-square of ten second intervals of data for each axis and forming a vector magnitude of the resulting data stream.

The interval RMS operation is expressed mathematically as:  $x_{RMS_k} = \sqrt{\frac{1}{M} \sum_{i=1}^M (x_{(k-1)M+i})^2}$ .

The same definitions apply for  $y$ ,  $M$ , and  $k$  as in the interval average computation. The resulting data streams are combined by a vector-magnitude operation.

### **Power Spectral Density versus Frequency versus Time Calculations**

In order to produce the spectrogram image, Power Spectral Densities were computed for successive time intervals (the length of the interval is equal to the time resolution). For the PSD computation, a Hanning window was applied. In order to combine all three axes into a single plot to show an overall level, a Vector-Magnitude (VM) operation was performed. Stated mathematically:

$$VM_k = \sqrt{PSD_{x_k}^2 + PSD_{y_k}^2 + PSD_{z_k}^2}.$$

By imaging the base 10 logarithm ( $\log_{10}$ ) magnitude as a color and stacking successive PSDs from left to right, variations of acceleration magnitude and frequency are shown as a function of time. Colors are assigned to discrete magnitude ranges, so that there are 64 colors assigned to the entire range of magnitudes shown.

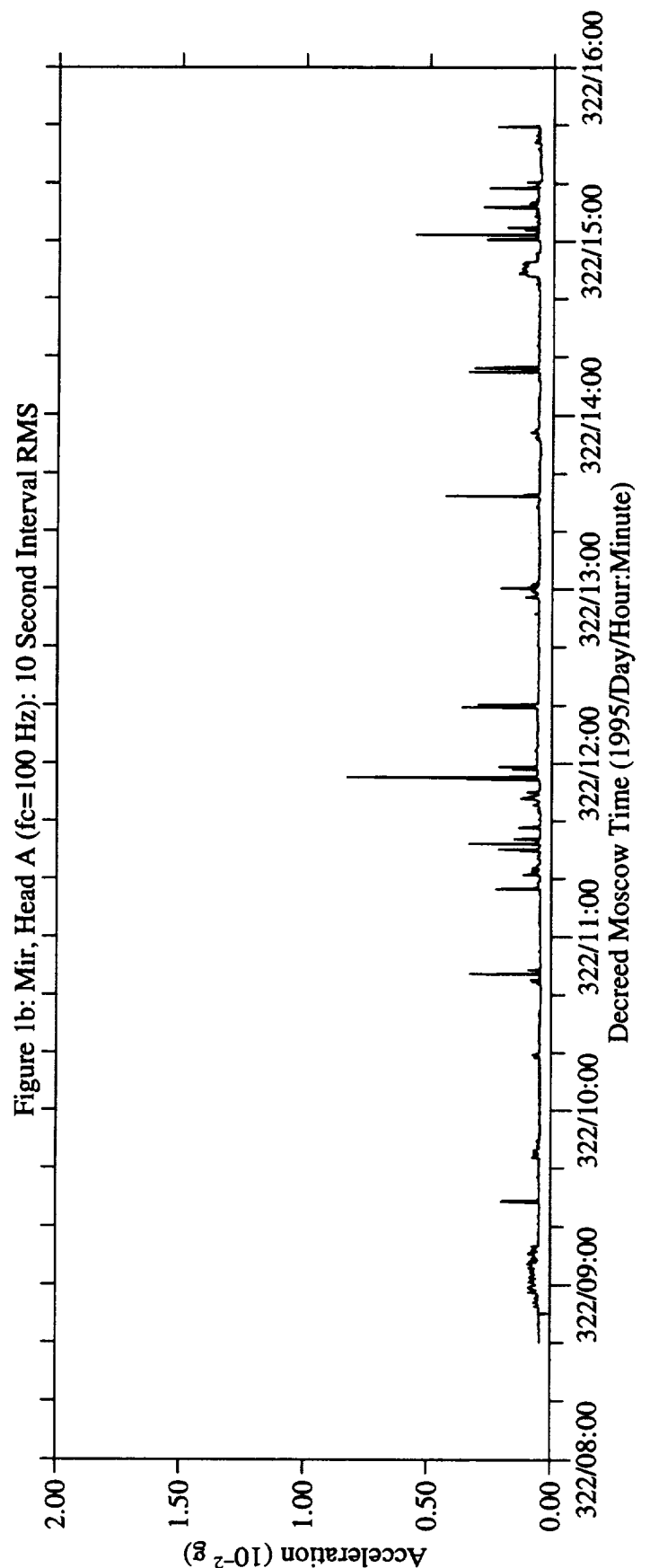
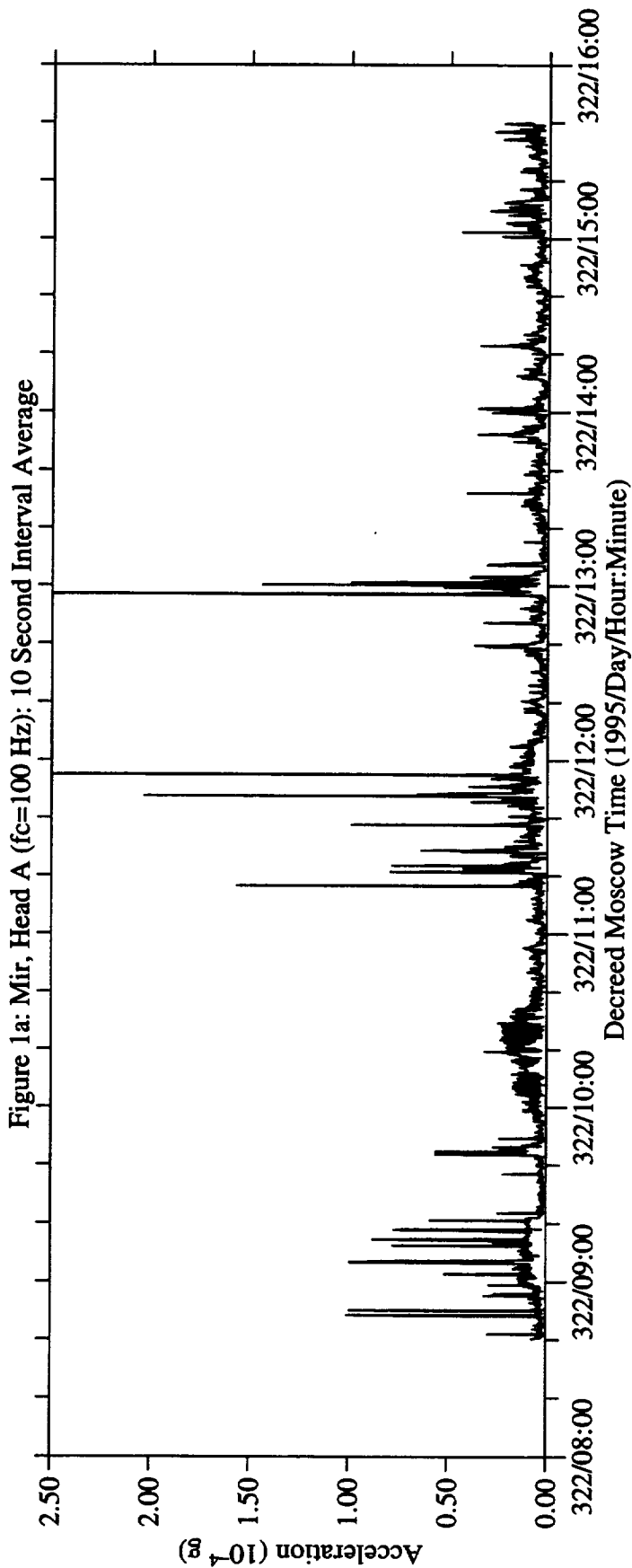
The colorbar limits are chosen in order to maximize the data value and visibility in a given set of spectrogram plots. Data which fall outside of these limits will be imaged as either the highest or lowest magnitude, depending on which side they have saturated. For this report, less than 1% of the total points lie below the lower limit, and less than 1% of the total points lie above the upper limit. If an area of interest seems to be saturated, care should be taken in that the actual values may lie above or below the color mapping shown on the plot.

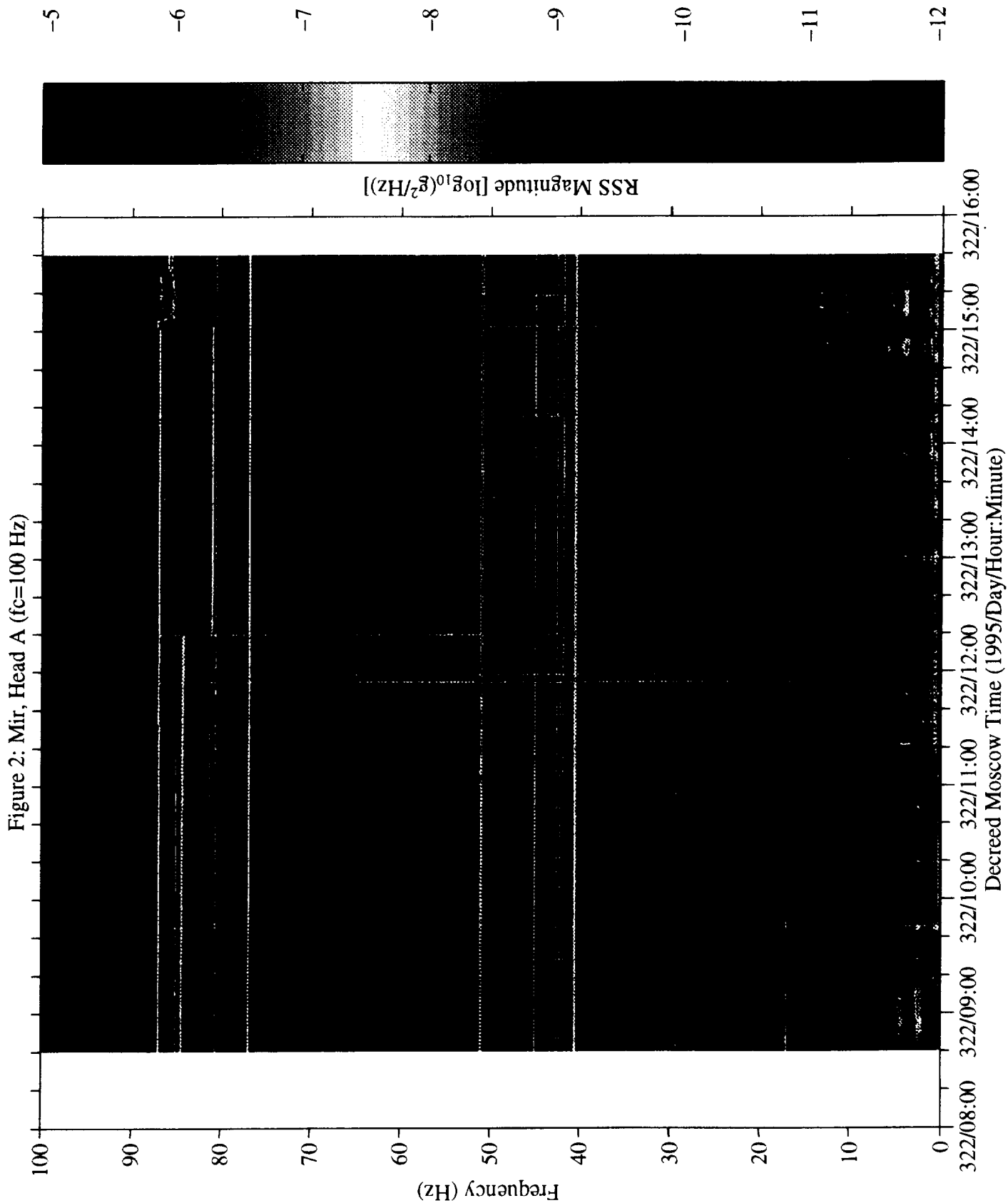
Due to the nature of spectrograms, care should be taken to not merely read a color's numeric value as being the "amount" of acceleration that is present at a given frequency. In order to get this type of information, the PSDs must be integrated between two frequencies. These frequencies (lower and upper) form the "band" of interest. The result of this integration is the  $g_{\text{RMS}}$  acceleration level in the  $[f_{\text{lower}}, f_{\text{upper}}]$  band. The PIMS group is able to provide this type of analysis on a per-request basis.

Plot gaps (if any exist) are shown by either white or dark blue areas on the page. Care should be taken to not mistake a plot gap (represented by a blue vertical band) with a quiet period. If a plot gap exists for an entire plot (or series of successive plots), a comment is placed on the page to let the user know there is a gap in the data. These "no data available" comments will not show exact times for which the data are not available, but will only indicate missing plots.

#### Contacting PIMS

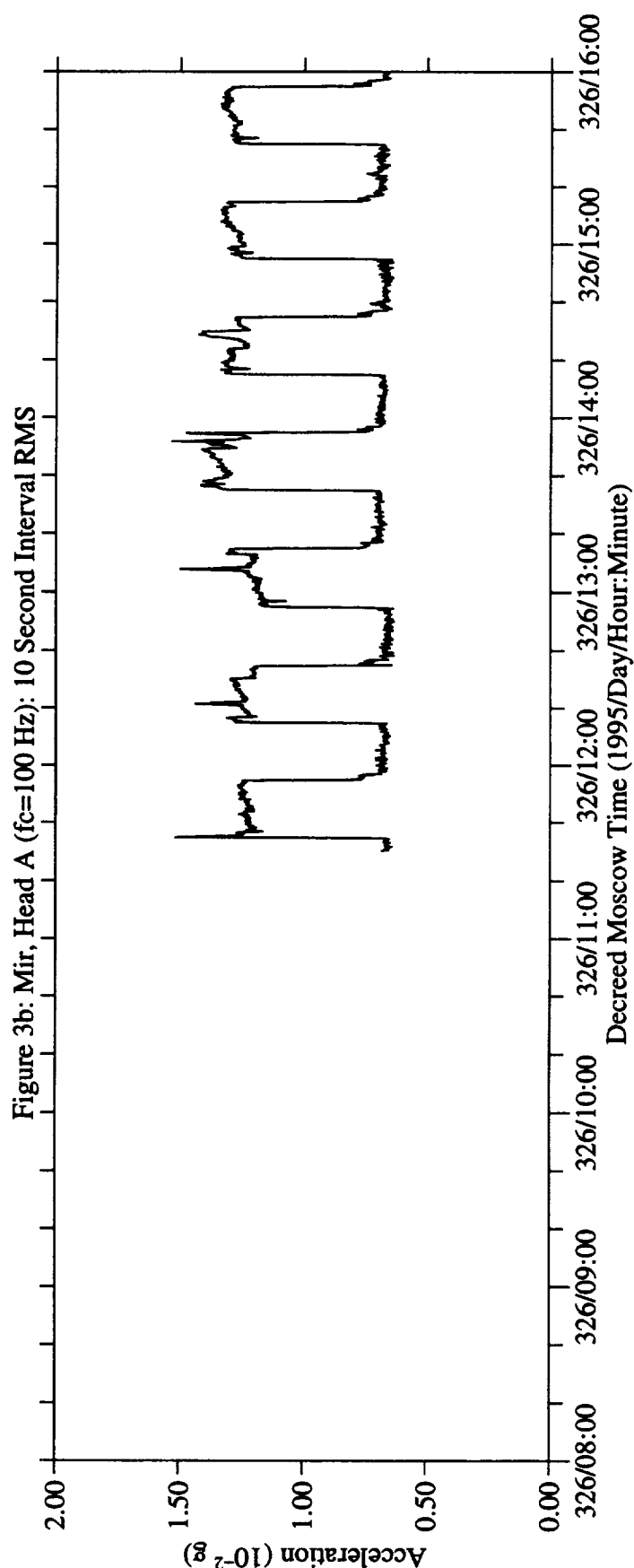
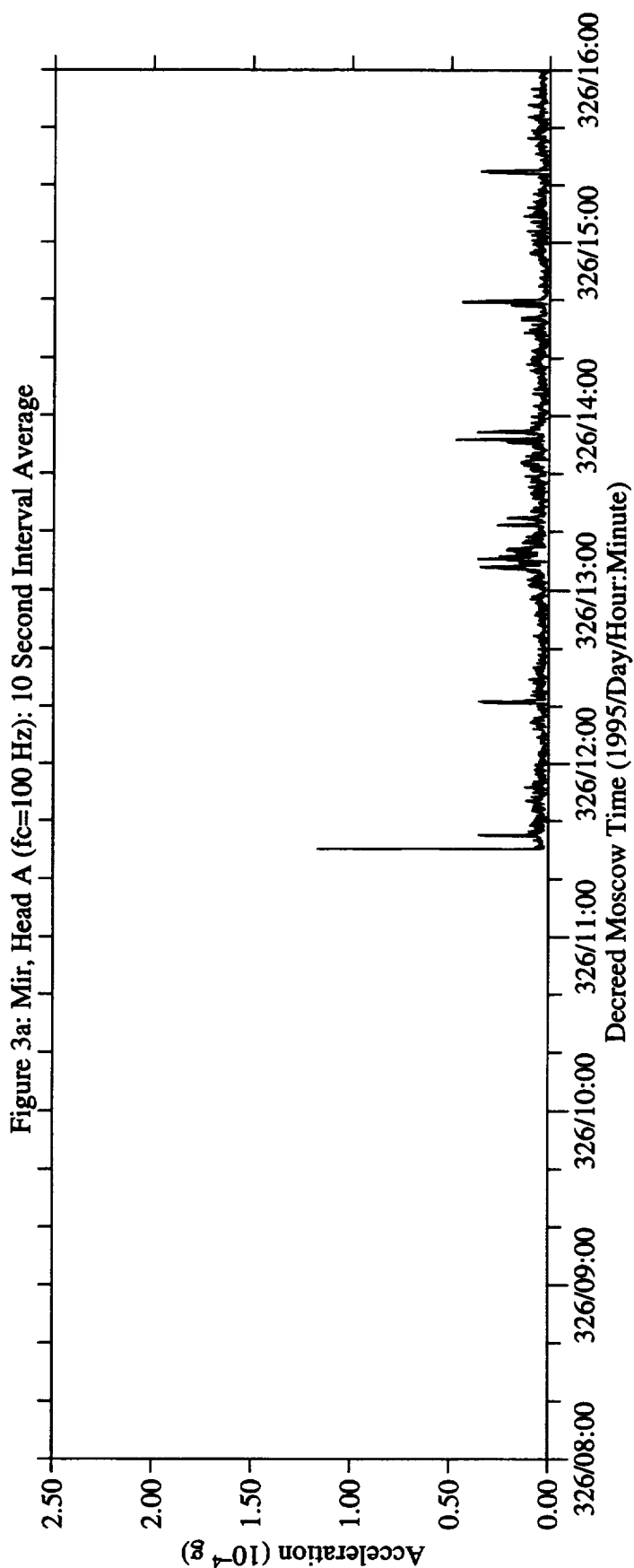
To request additional analysis or information, users are encouraged to send an e-mail to [pims@lerc.nasa.gov](mailto:pims@lerc.nasa.gov), or FAX a request to (216) 433-8545.



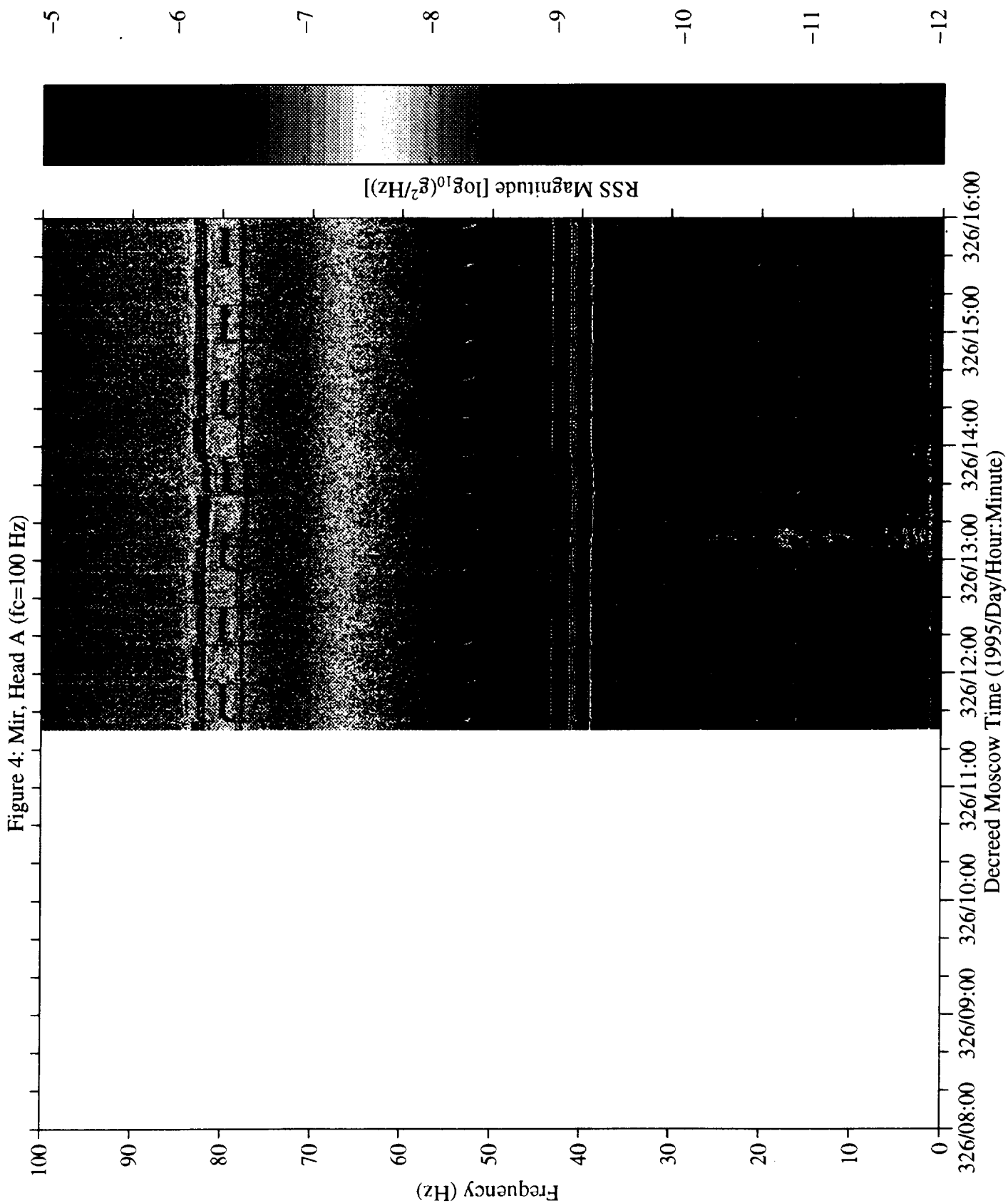


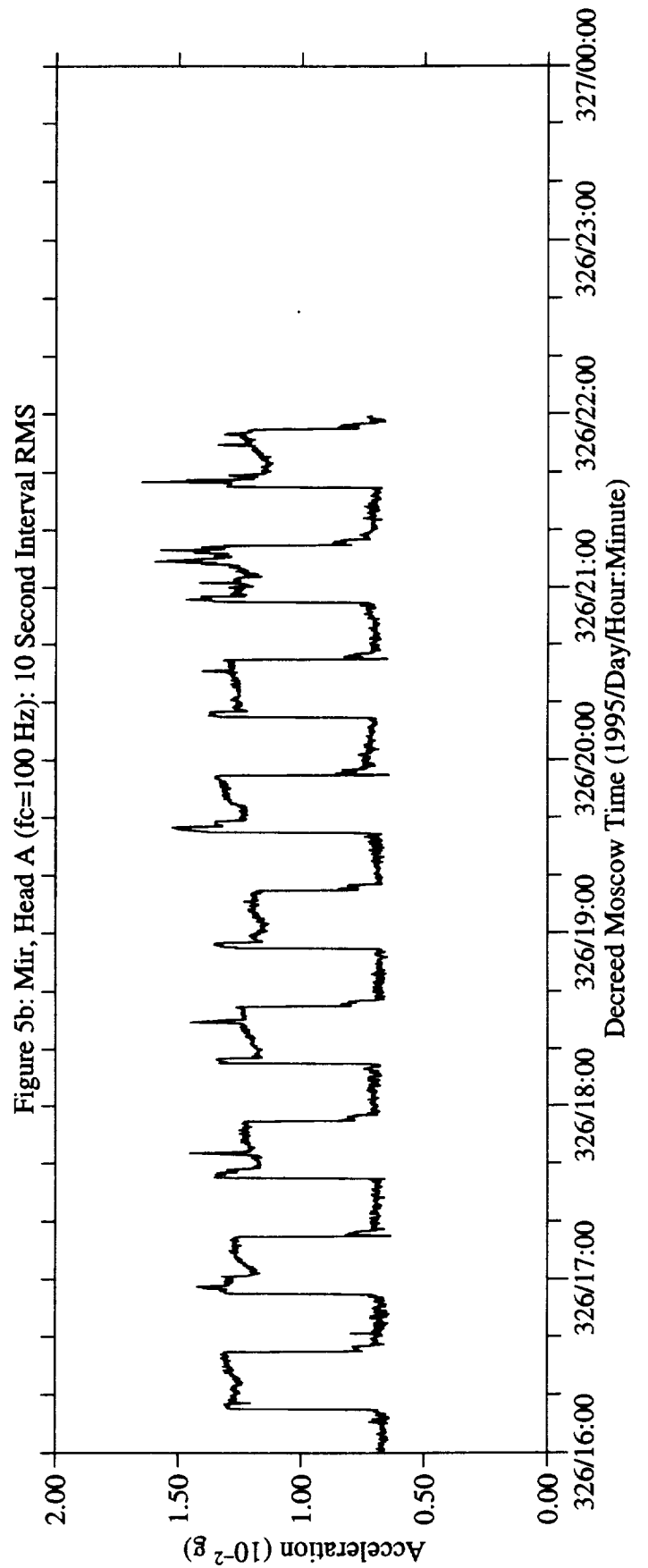
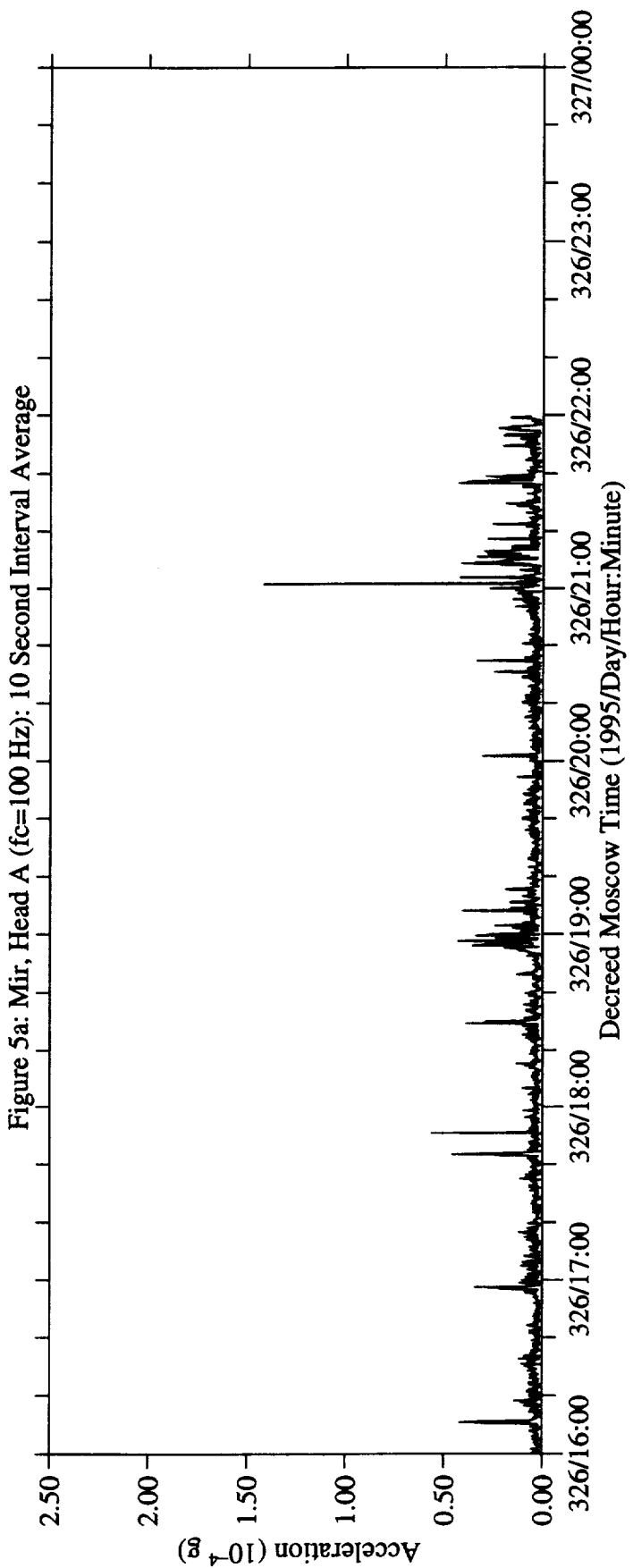
No data are available  
from 322/16:00:00 to 326/08:00:00

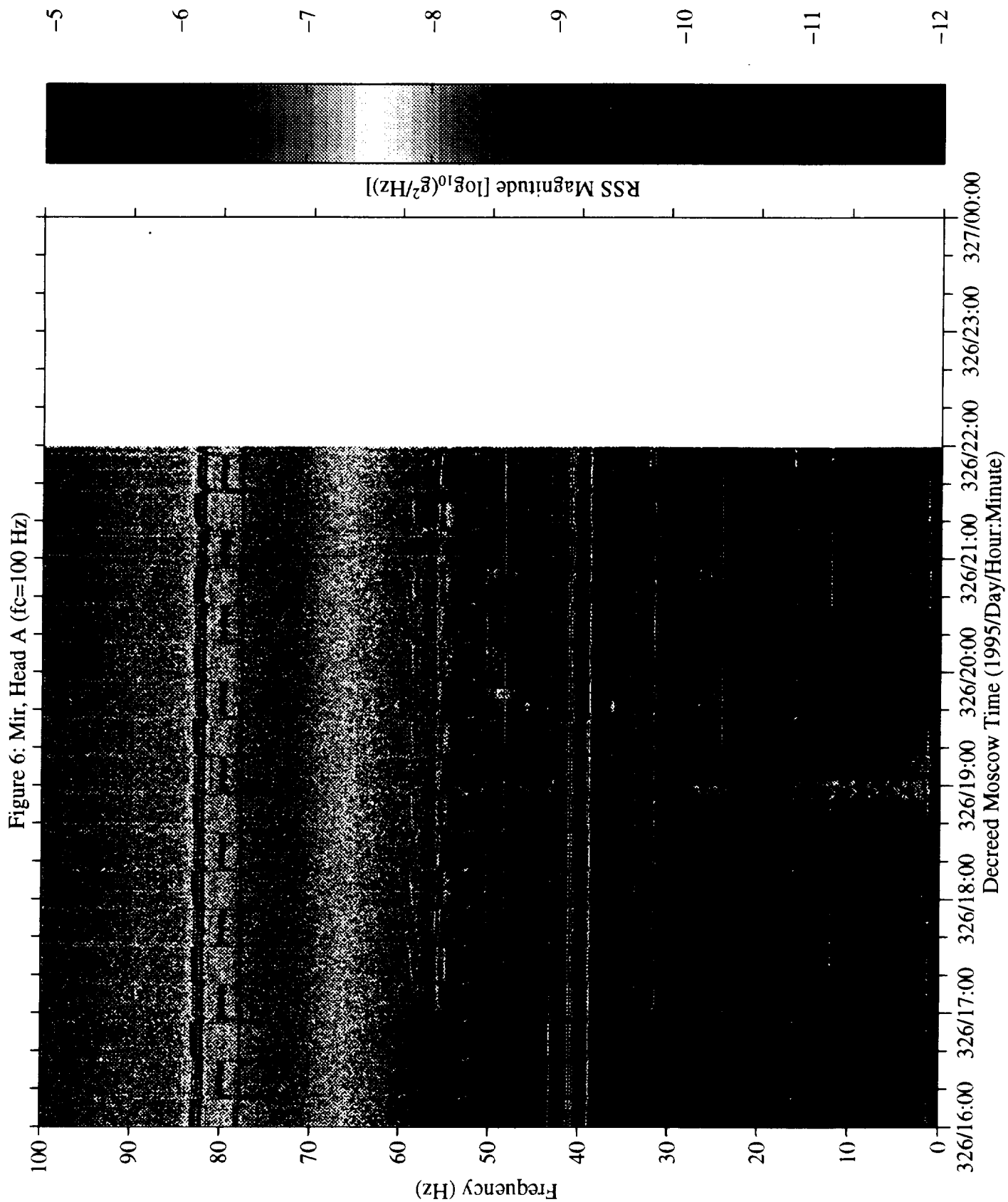
No data are available  
from 322/16:00:00 to 326/08:00:00











No data are available  
from 327/00:00:00 to 334/08:00:00

No data are available  
from 327/00:00:00 to 334/08:00:00

Figure 7a: Mir, Head A (fc=100 Hz): 10 Second Interval Average

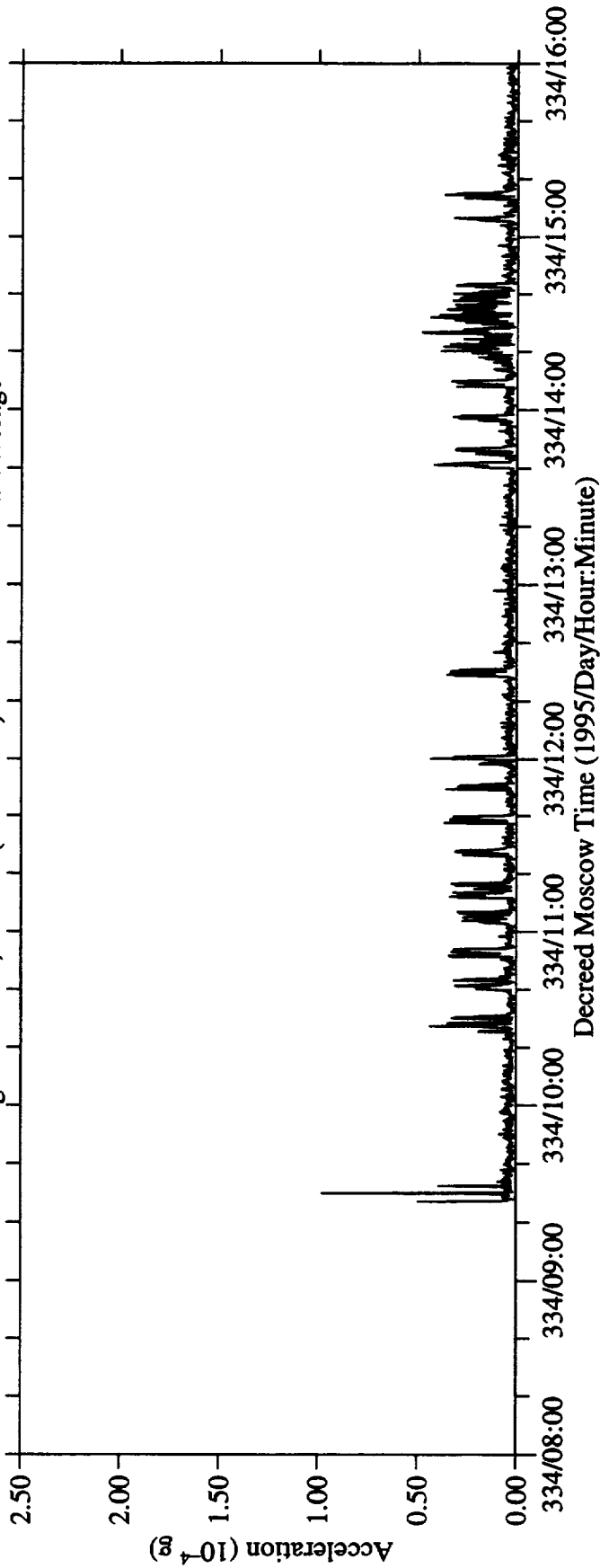
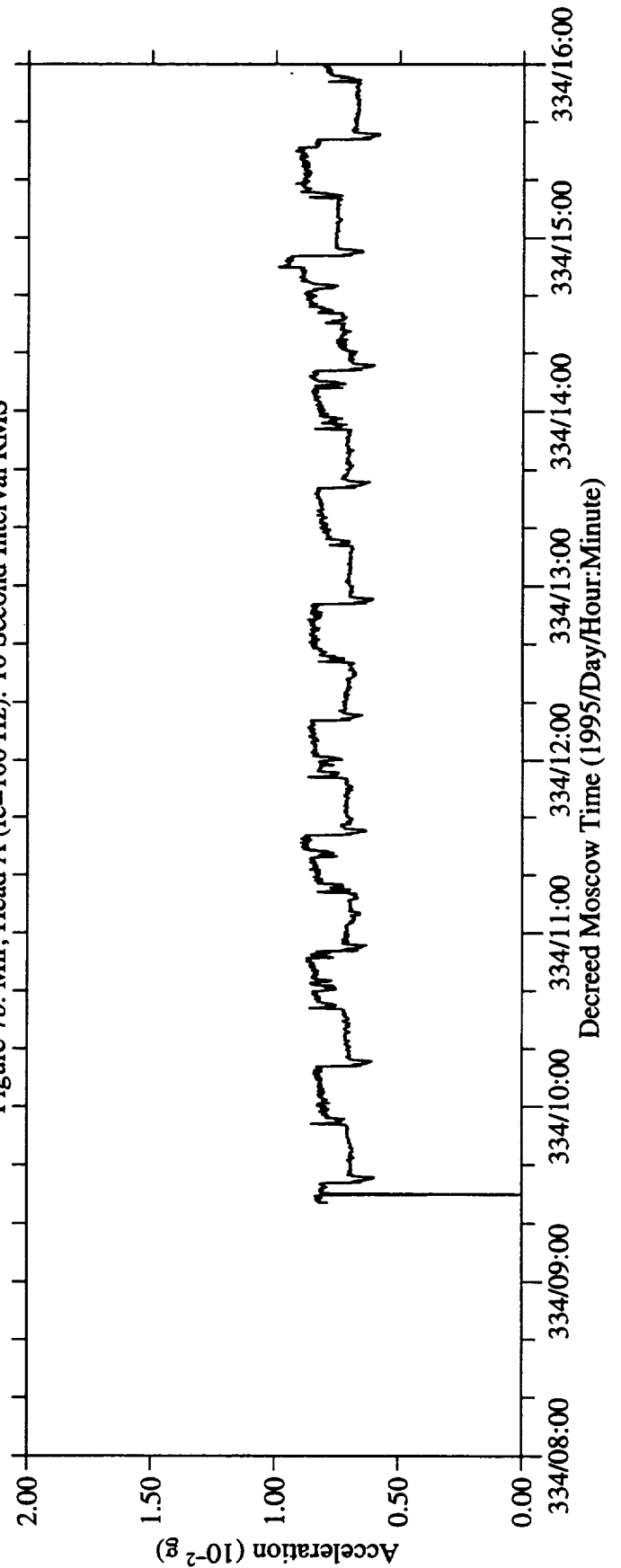
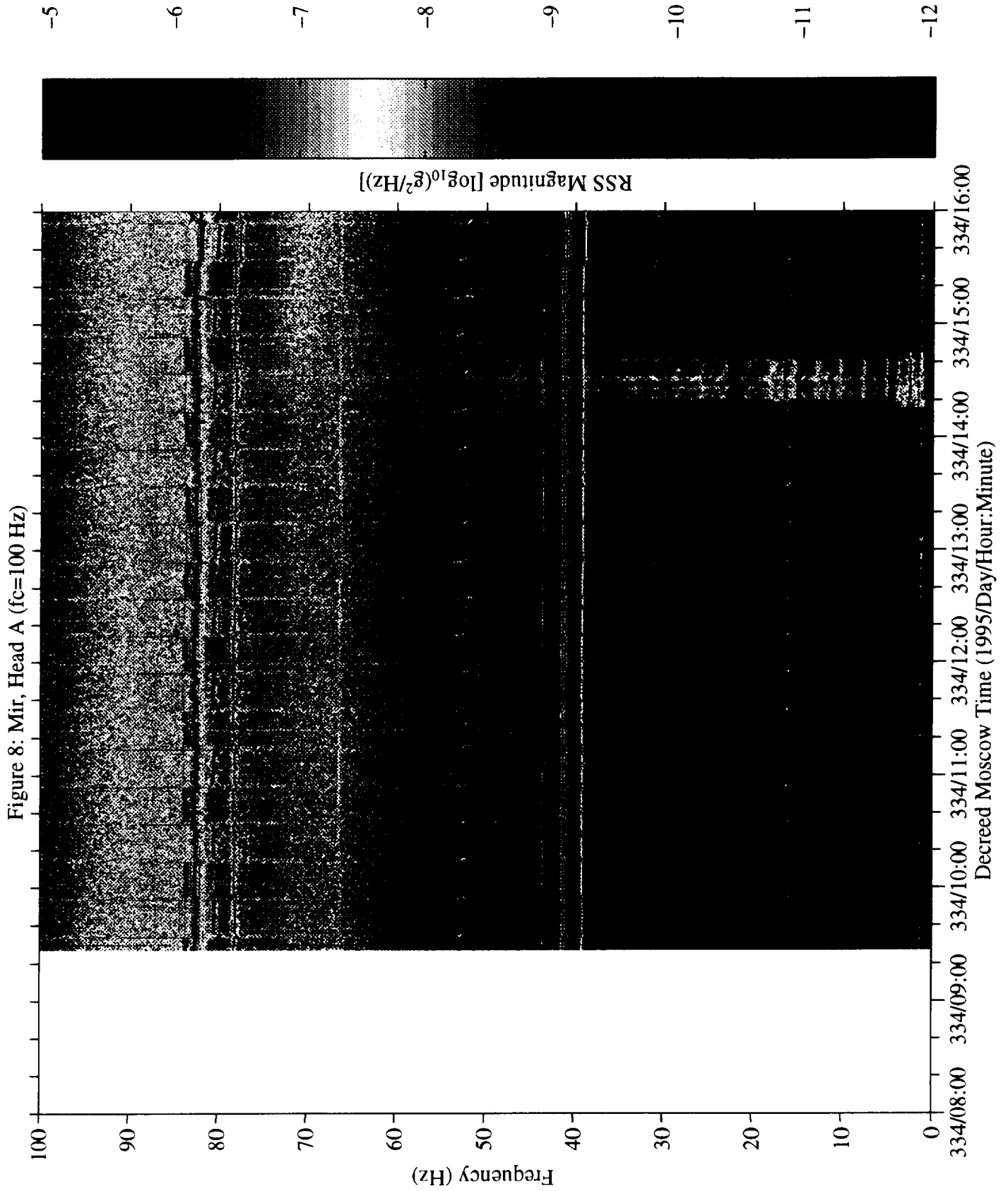
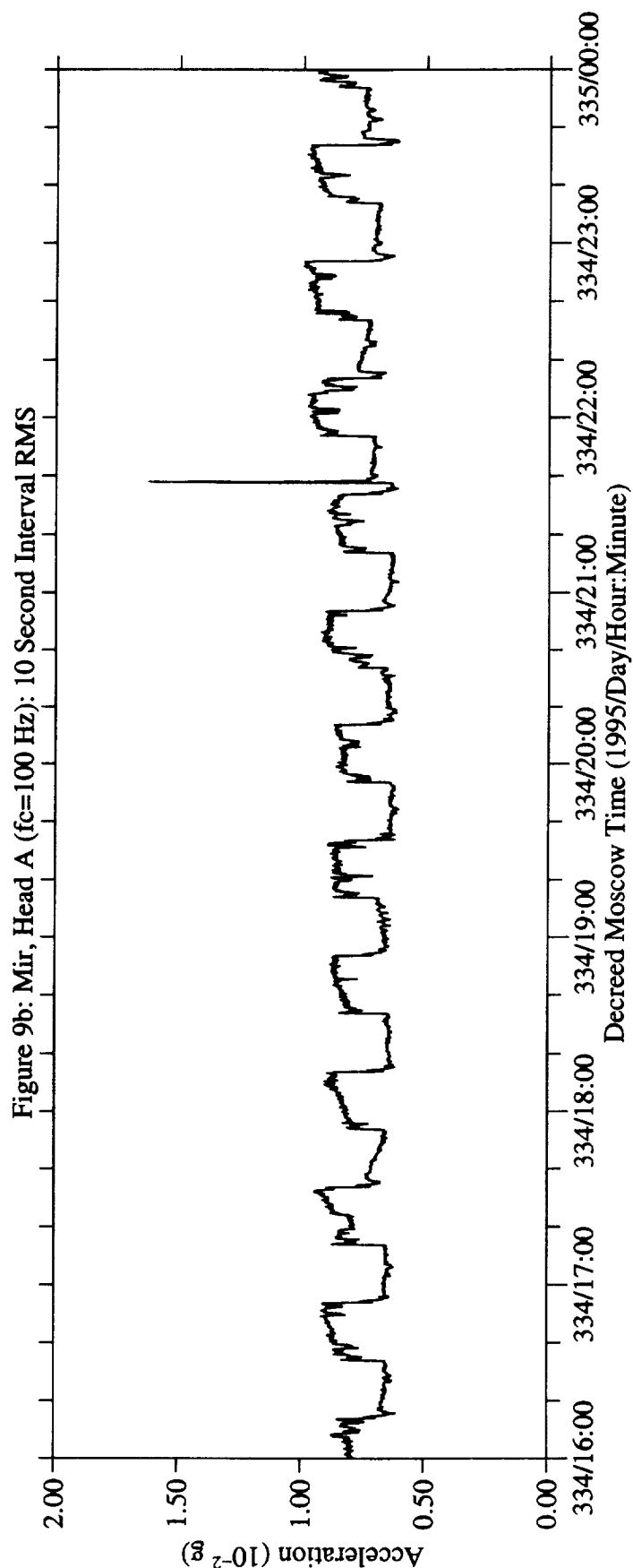
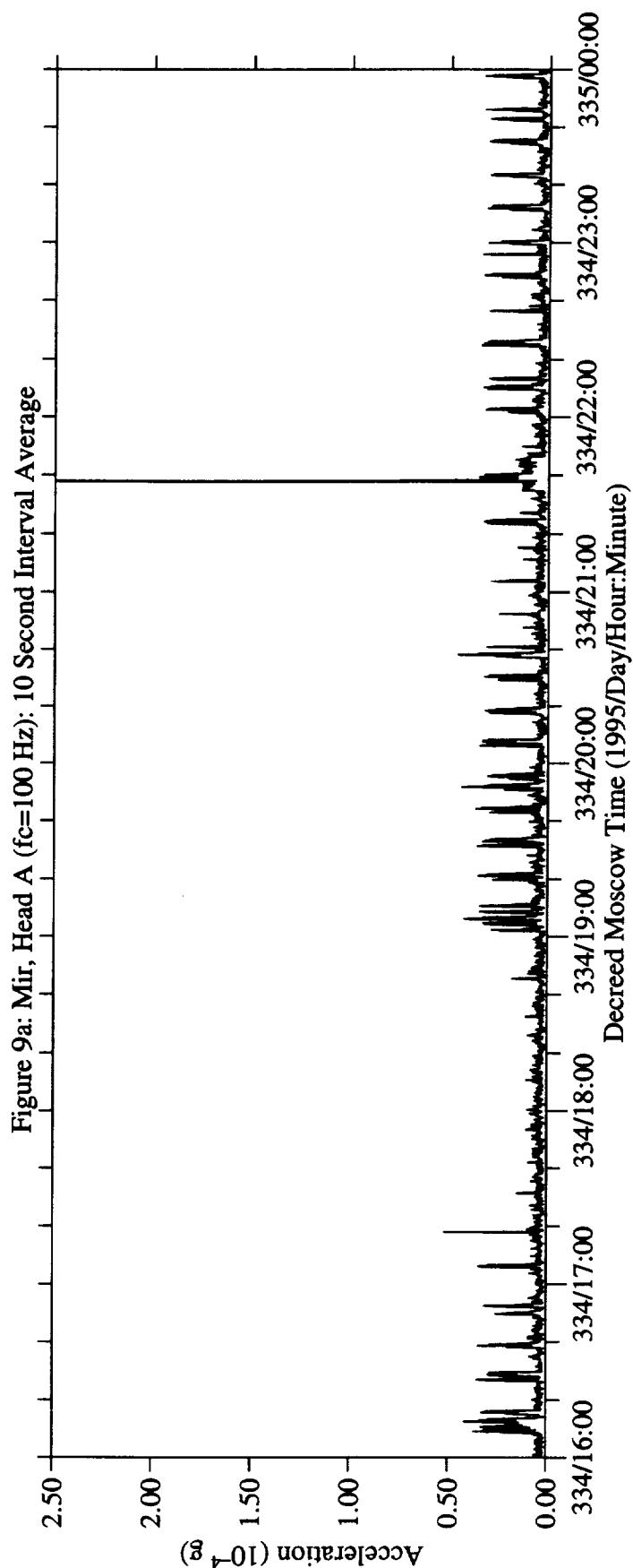


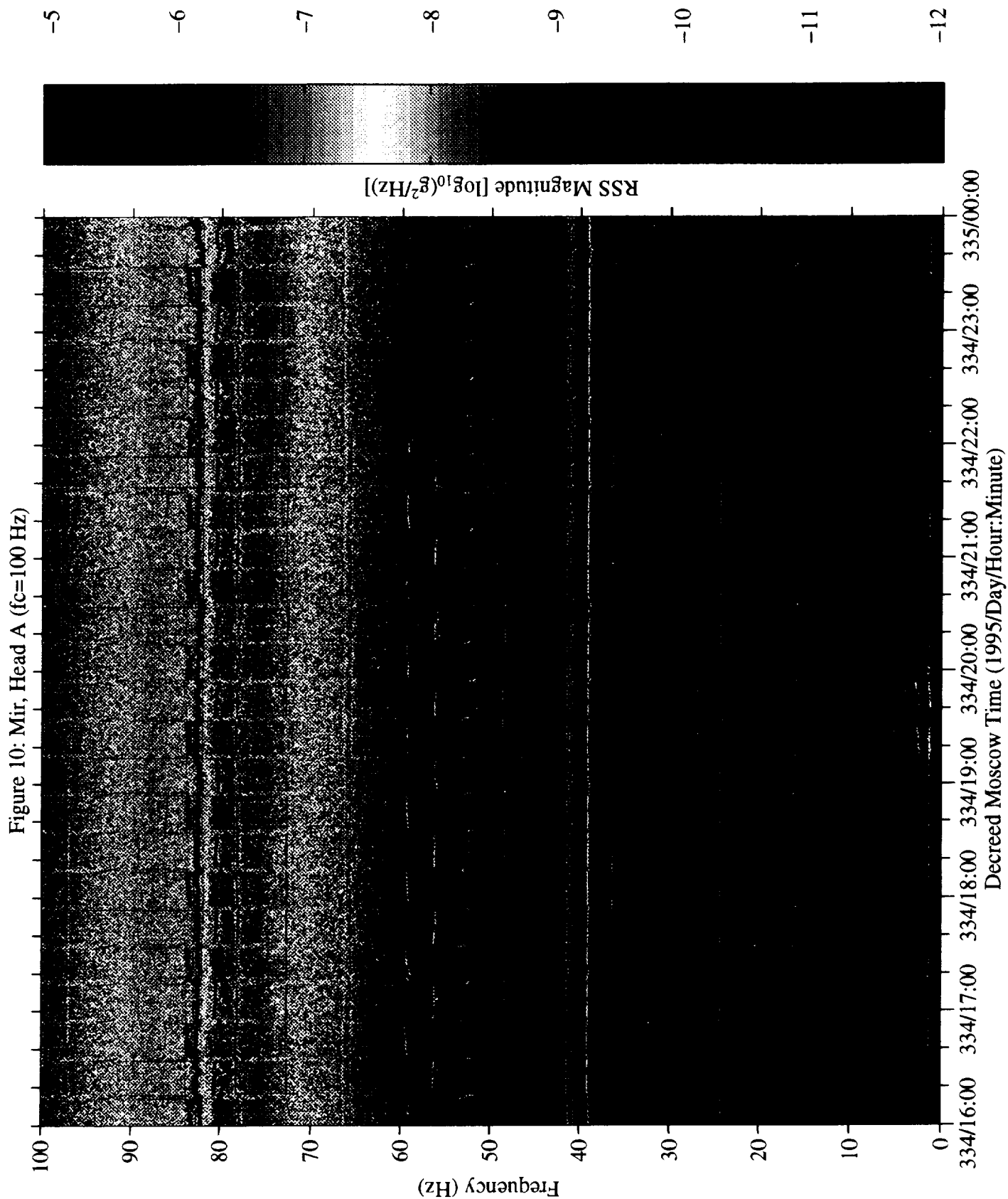
Figure 7b: Mir, Head A (fc=100 Hz): 10 Second Interval RMS

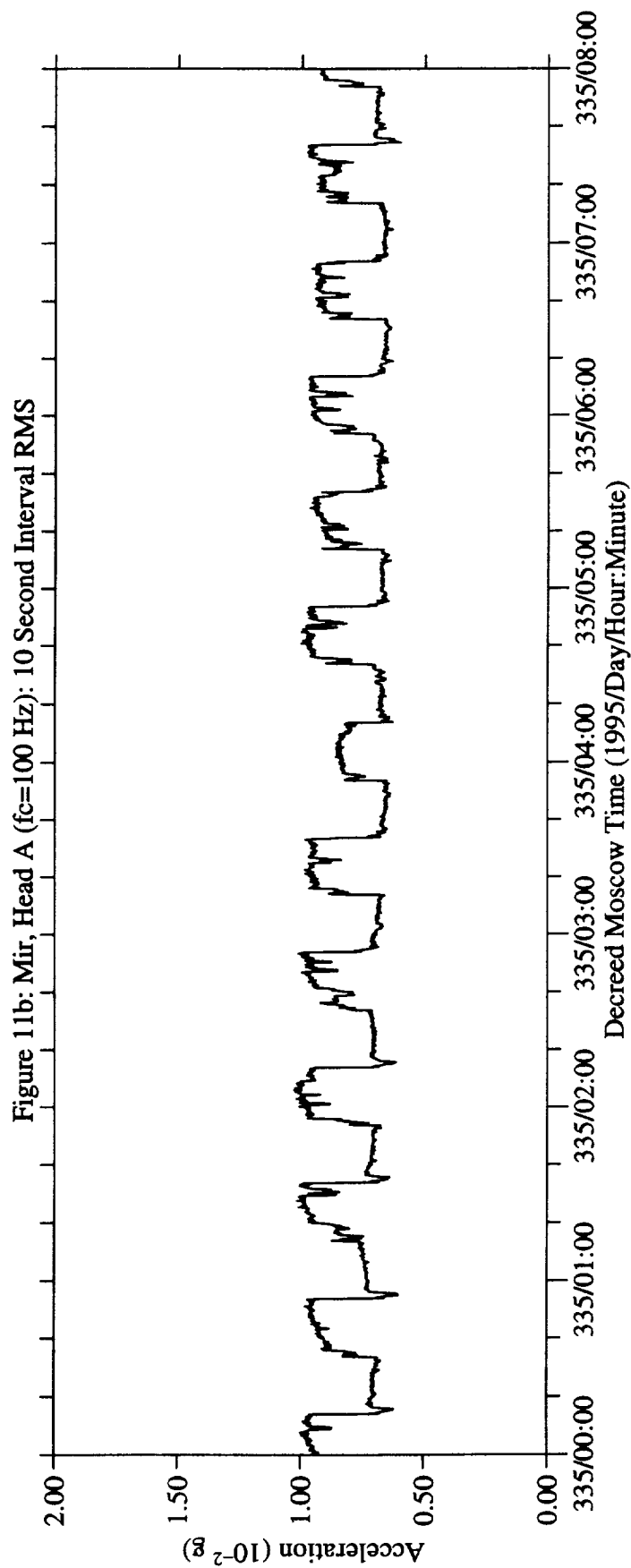
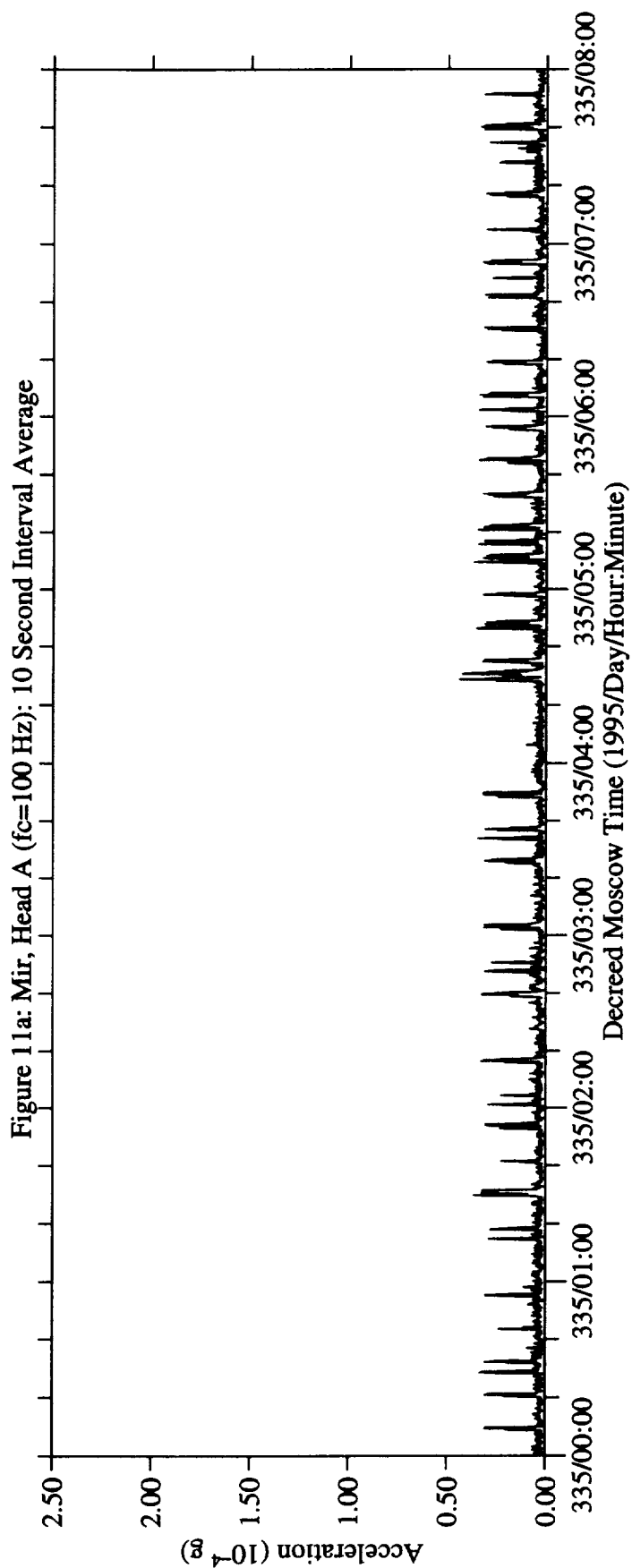


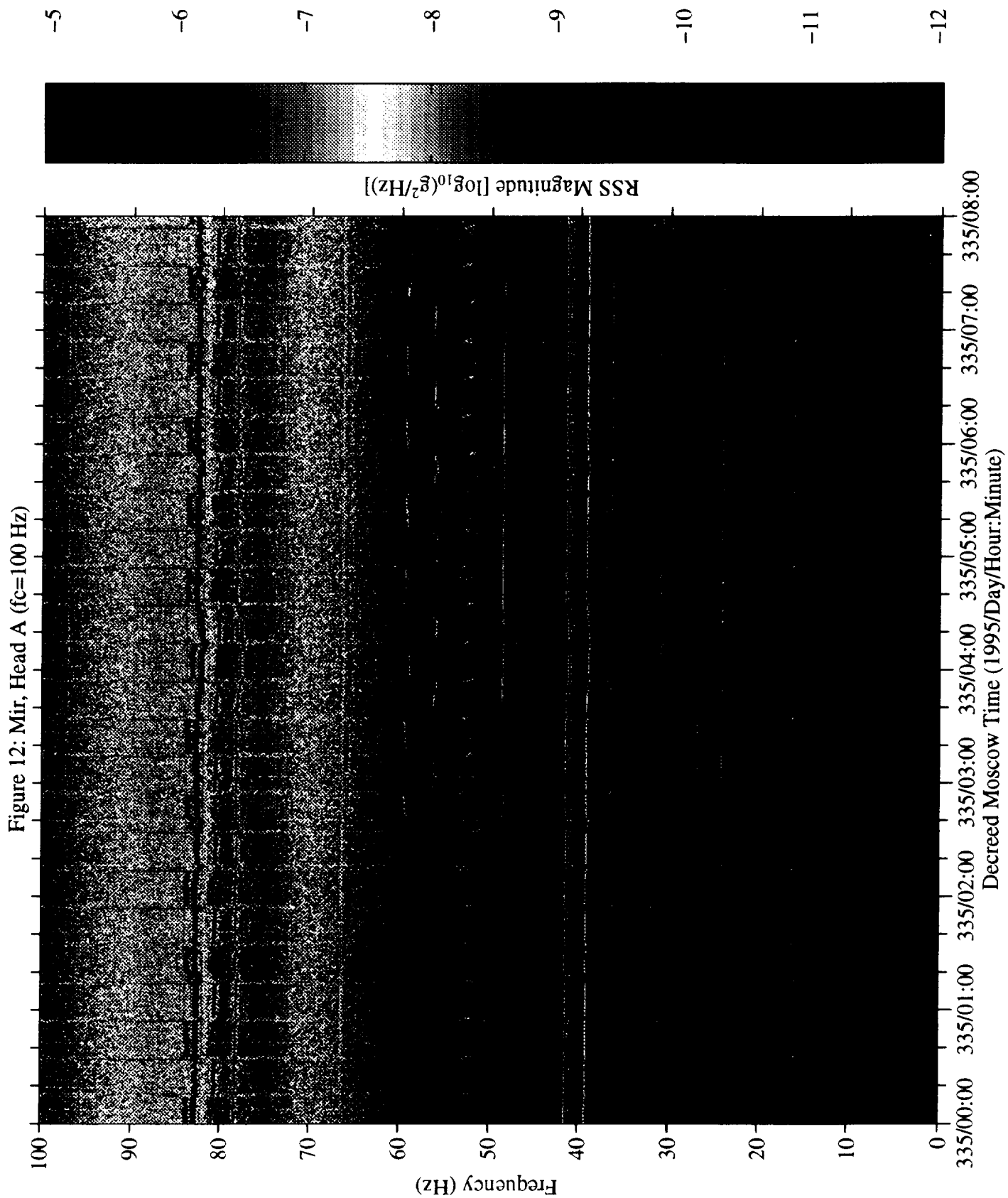


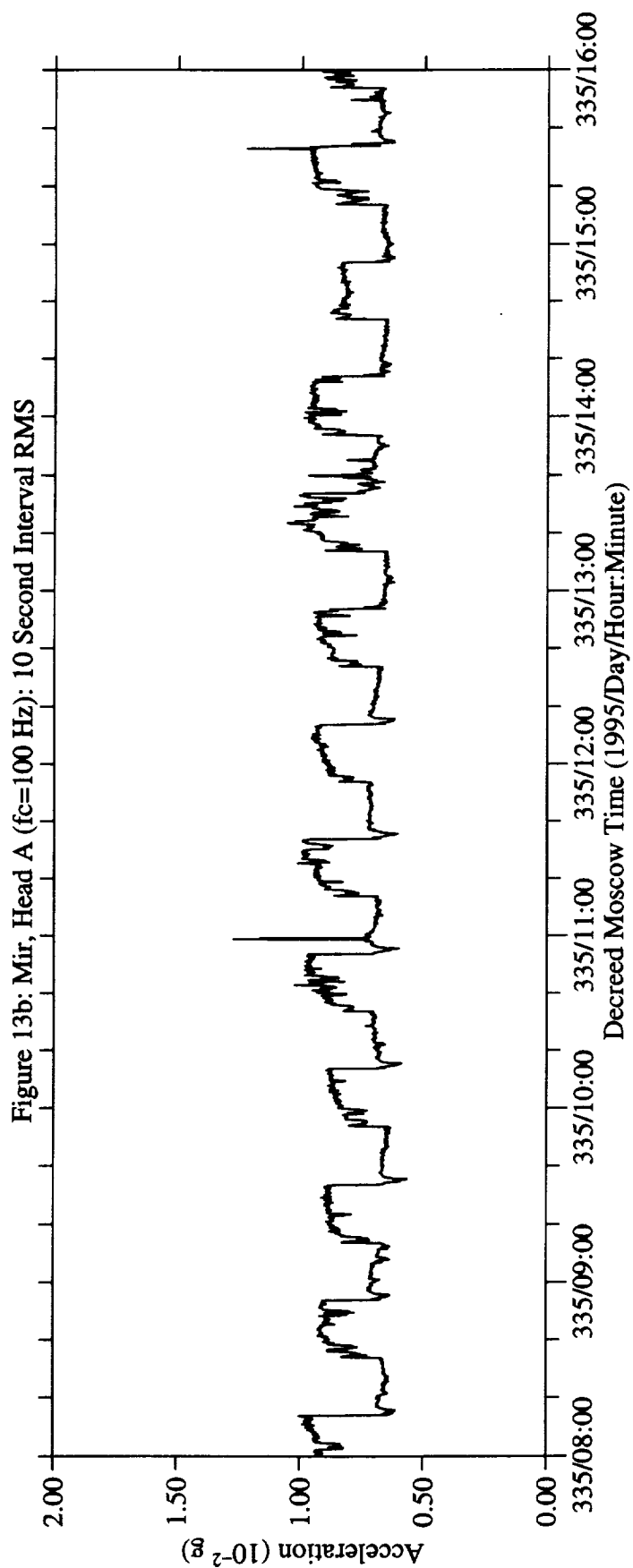
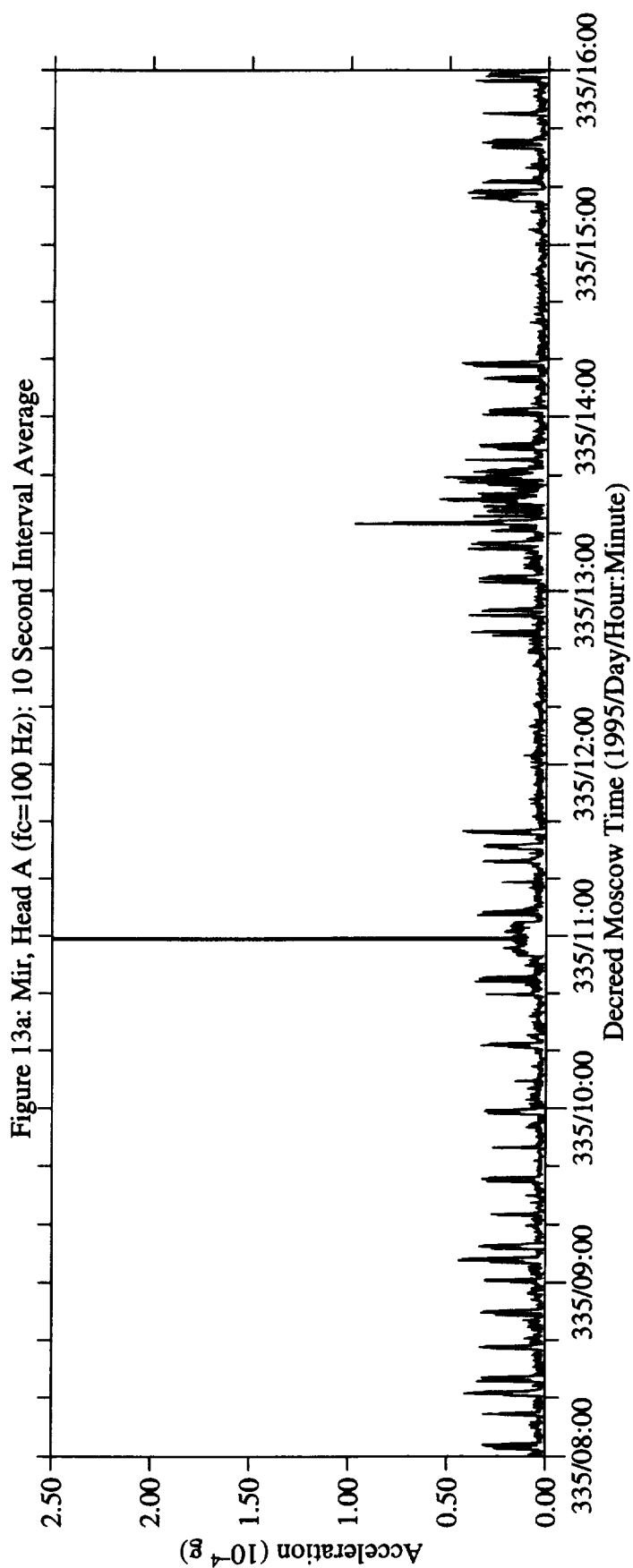


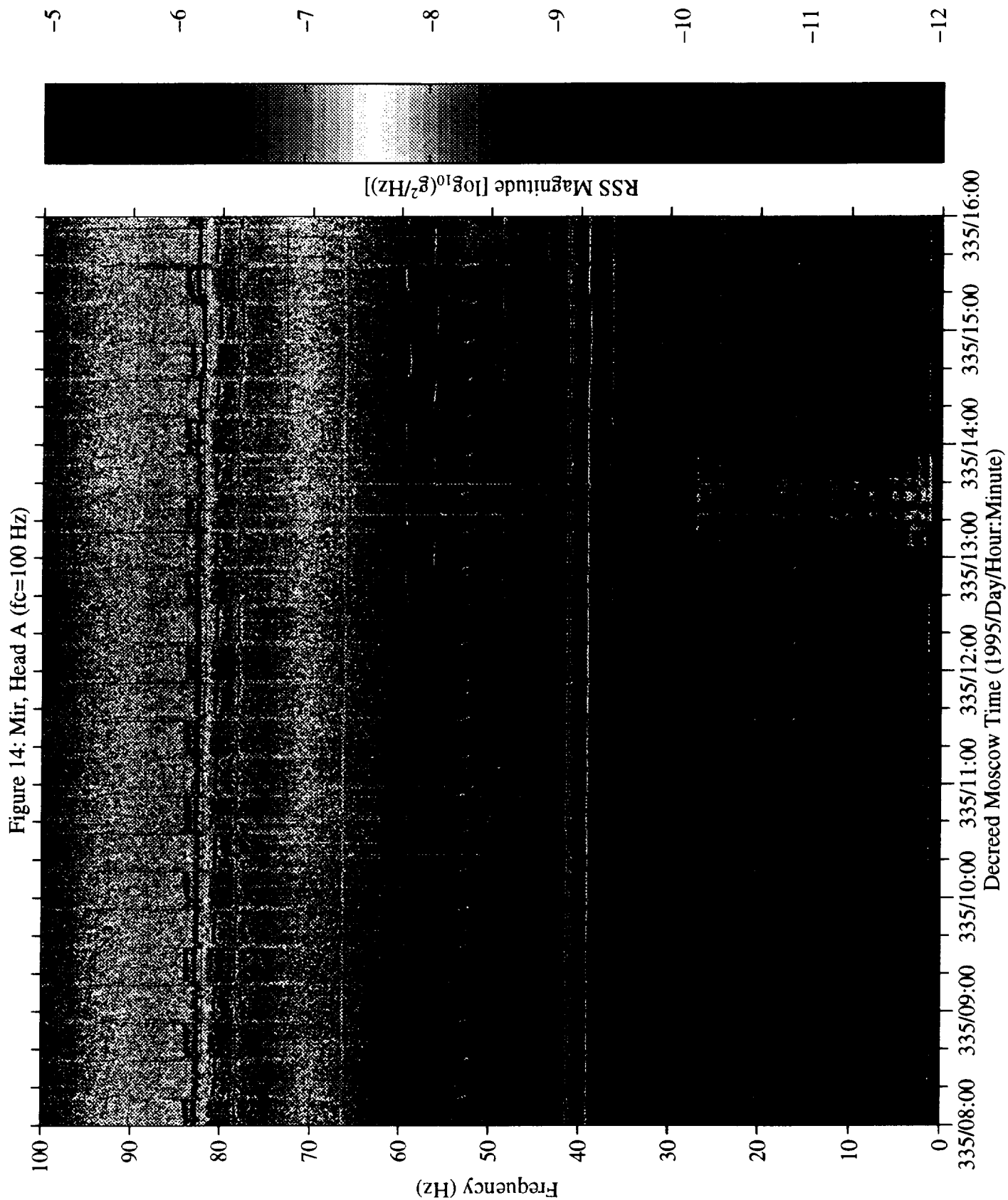


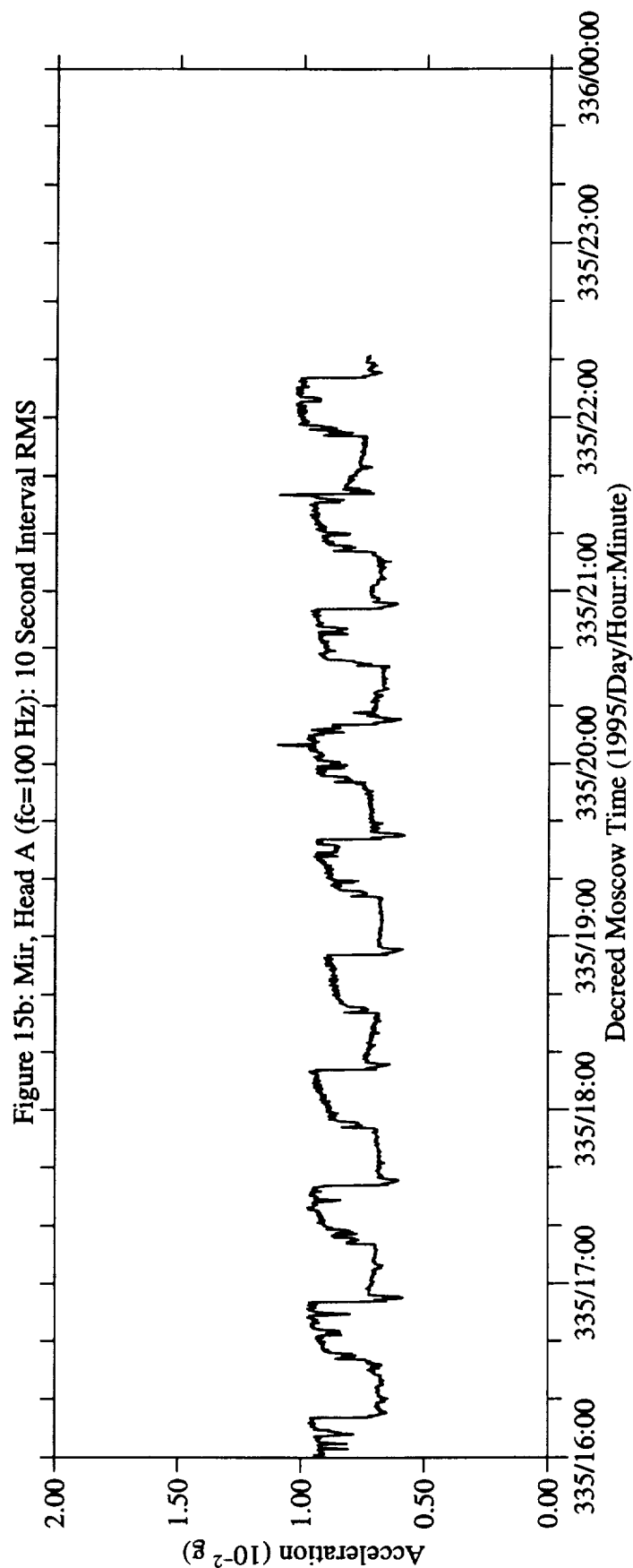
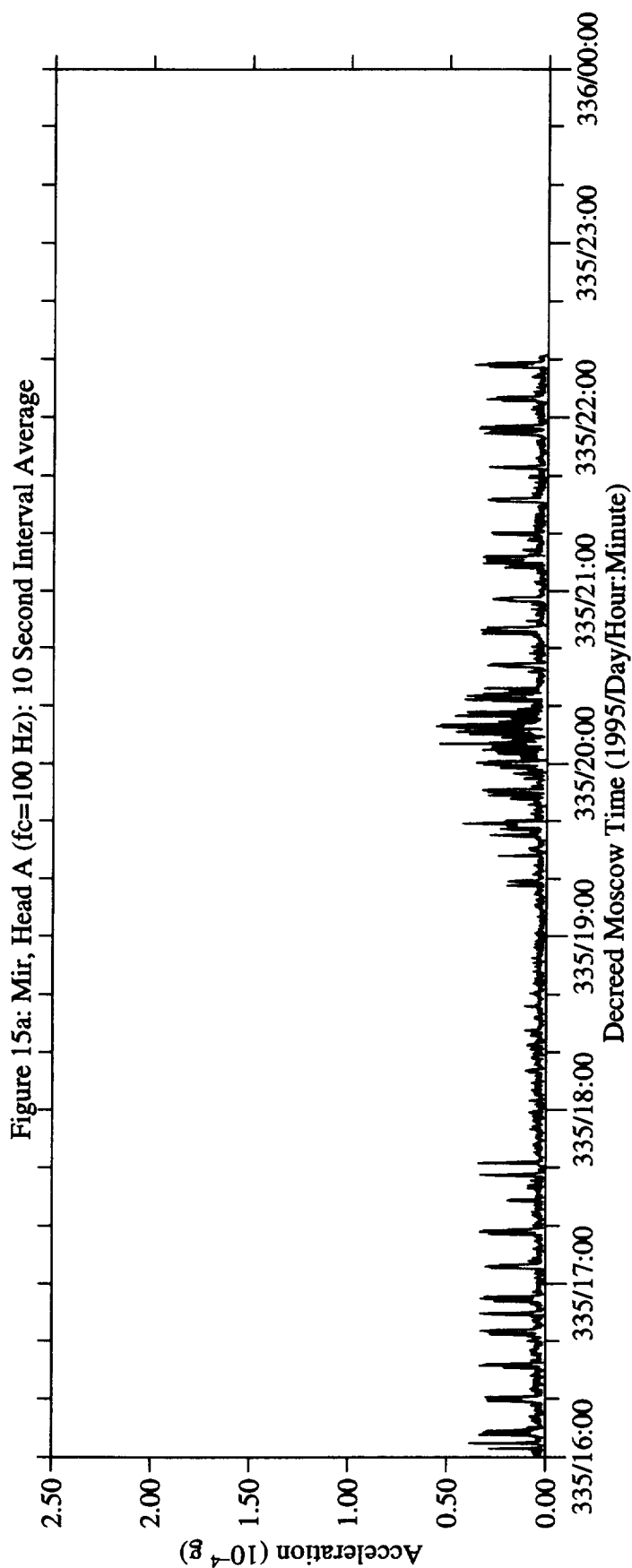


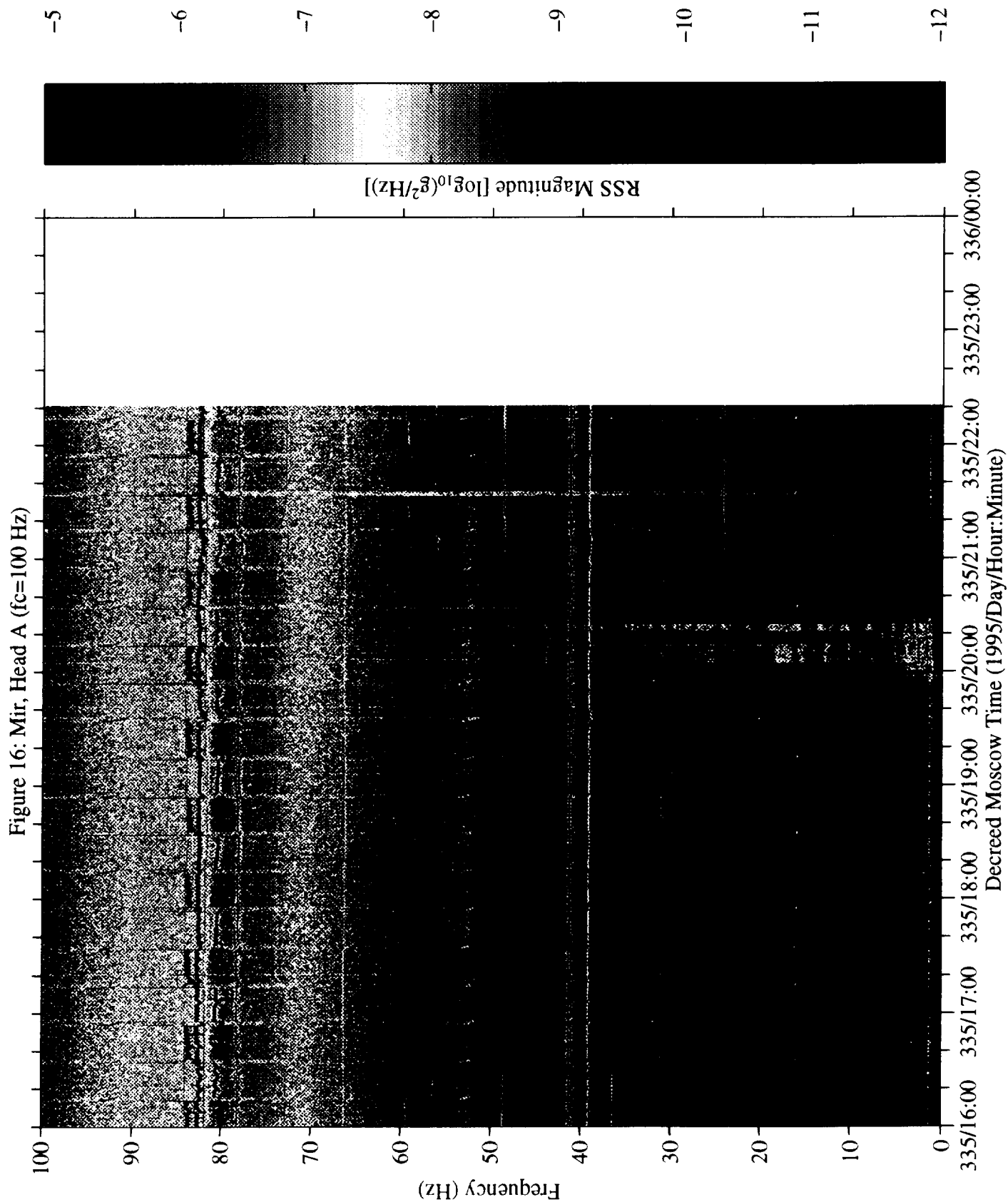












No data are available  
from 336/00:00:00 to 340/16:00:00



No data are available  
from 336/00:00:00 to 340/16:00:00

Figure 17a: Mir, Head A (fc=100 Hz): 10 Second Interval Average

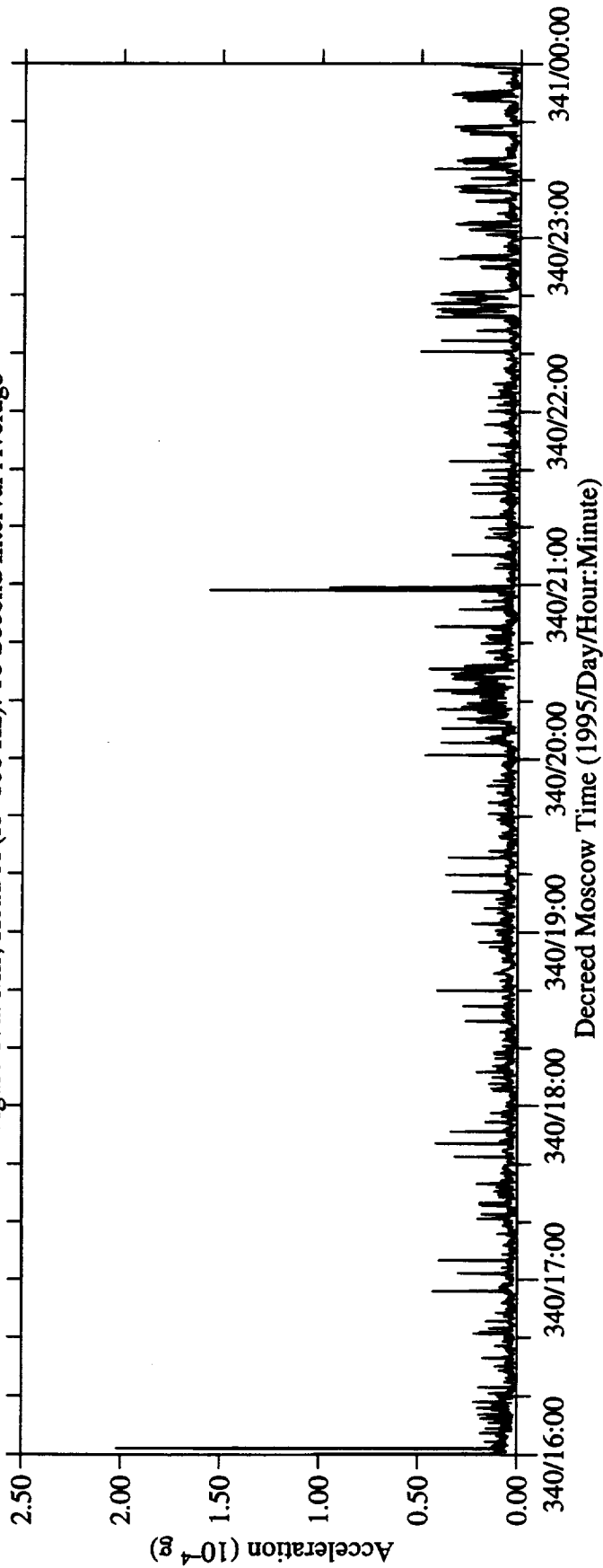
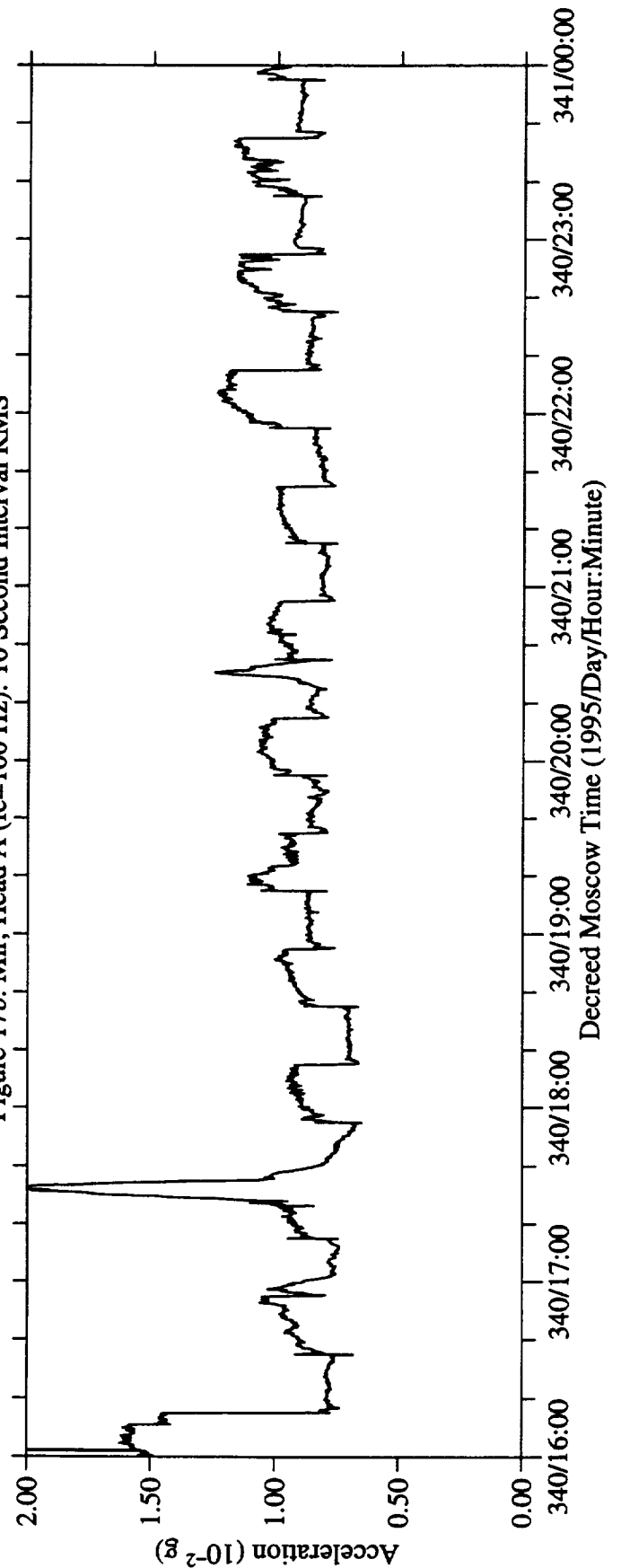
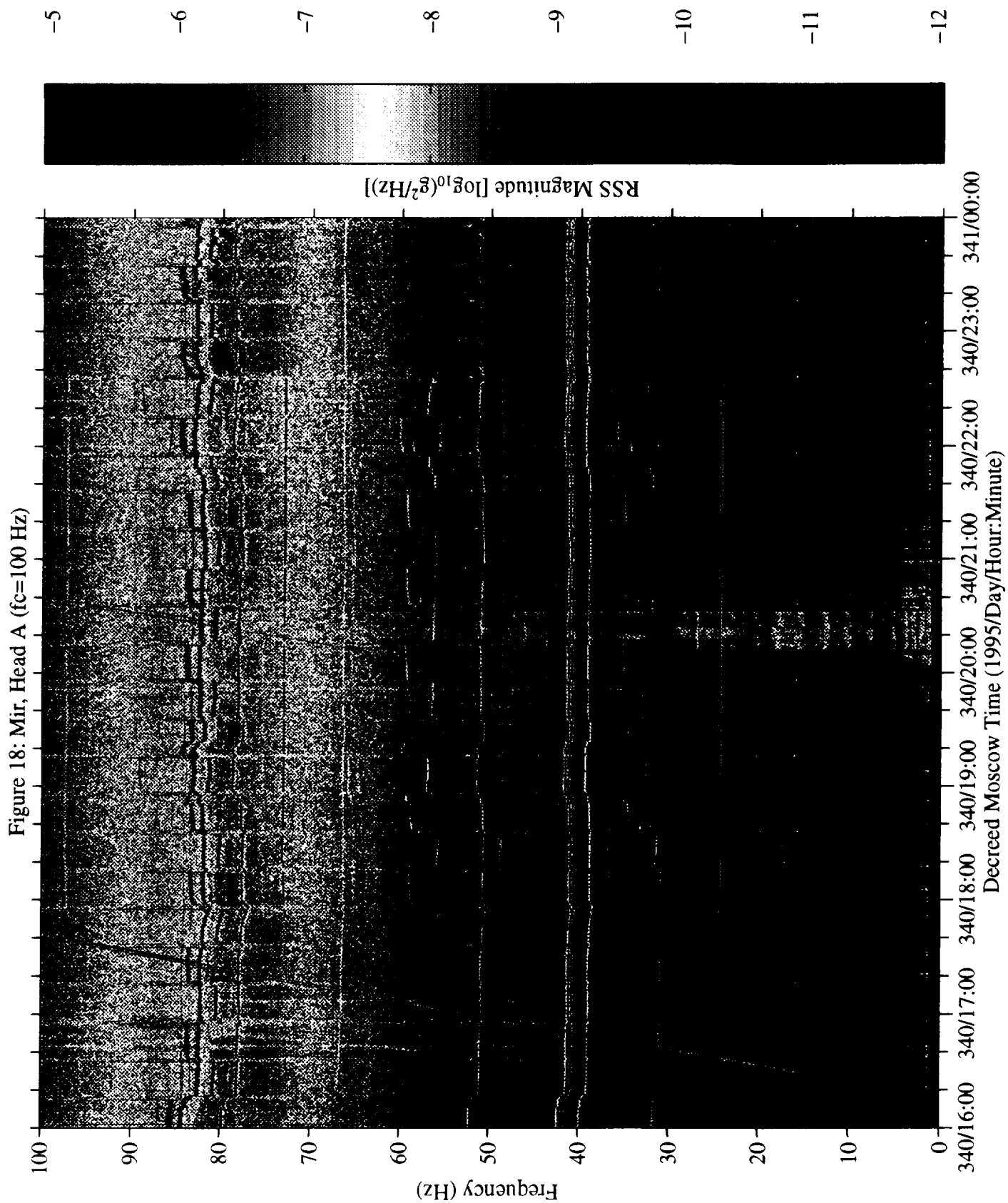
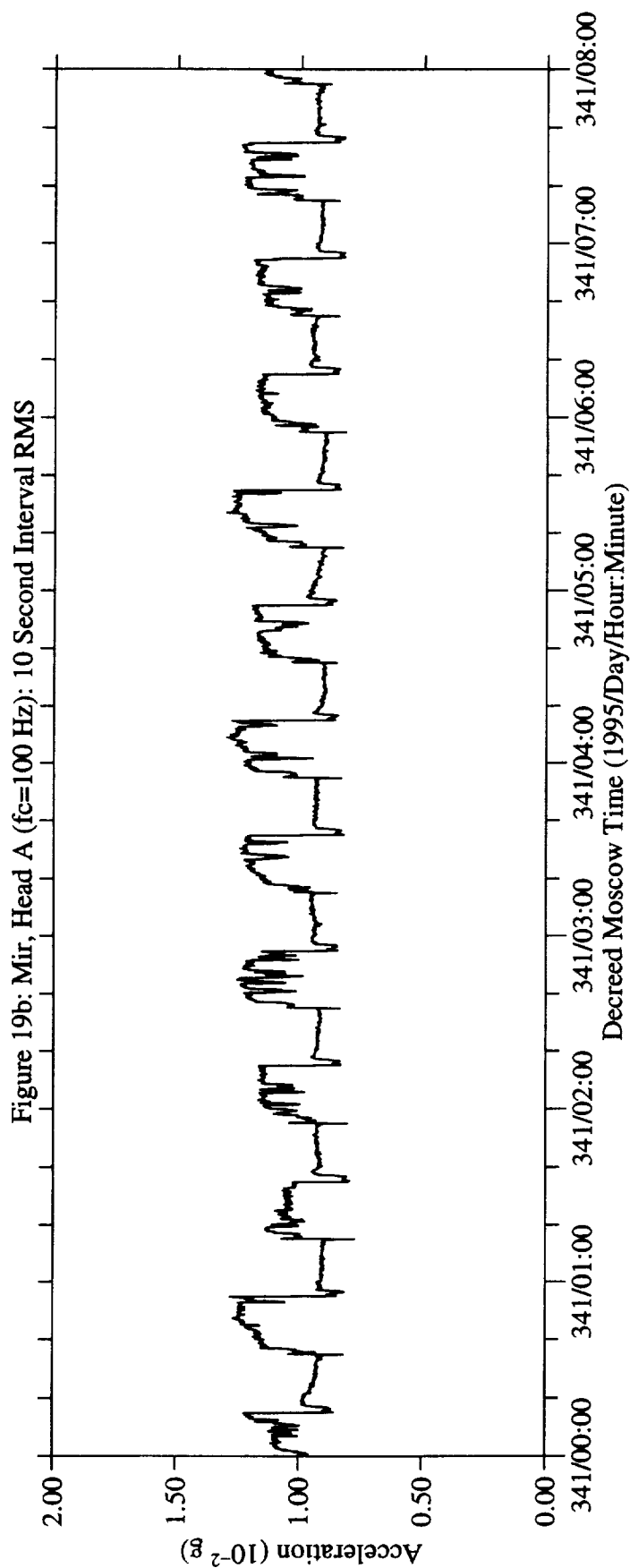
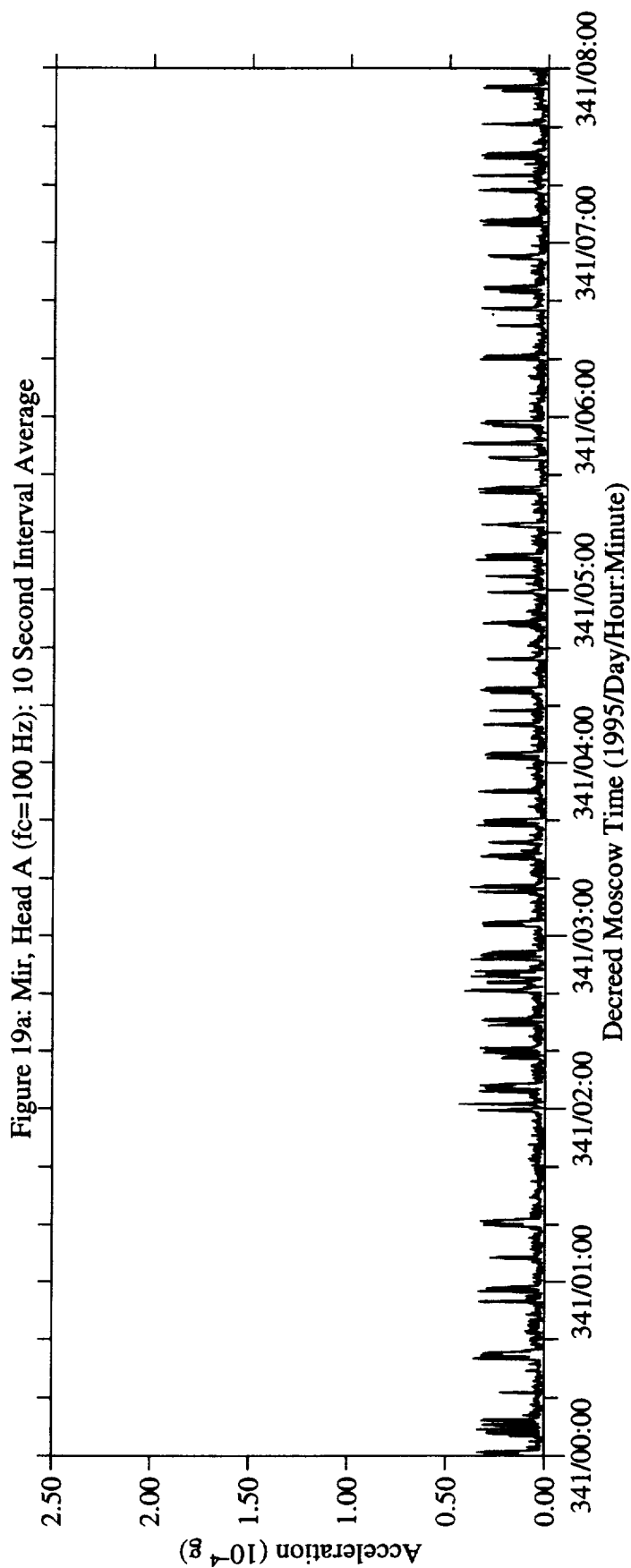
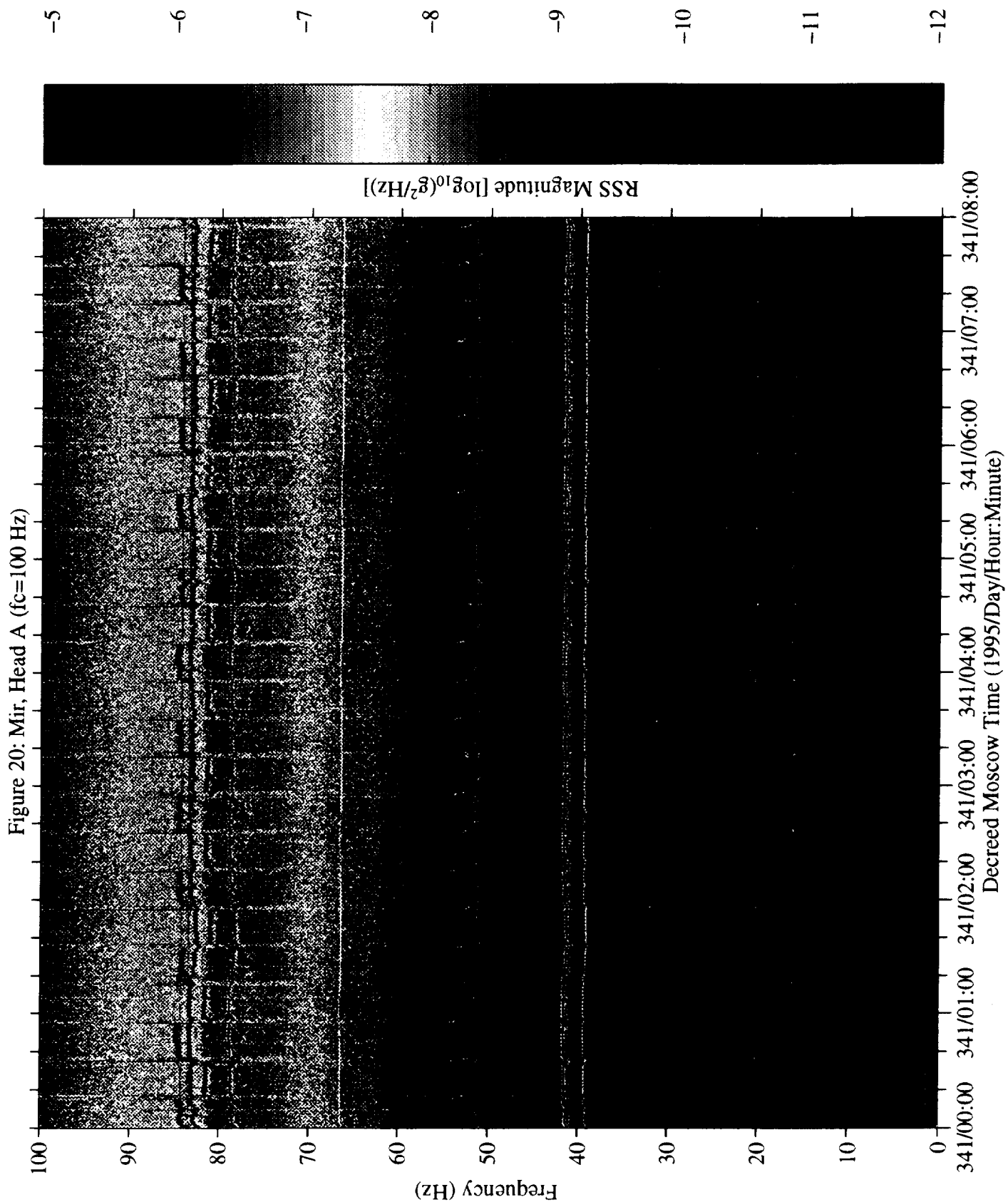


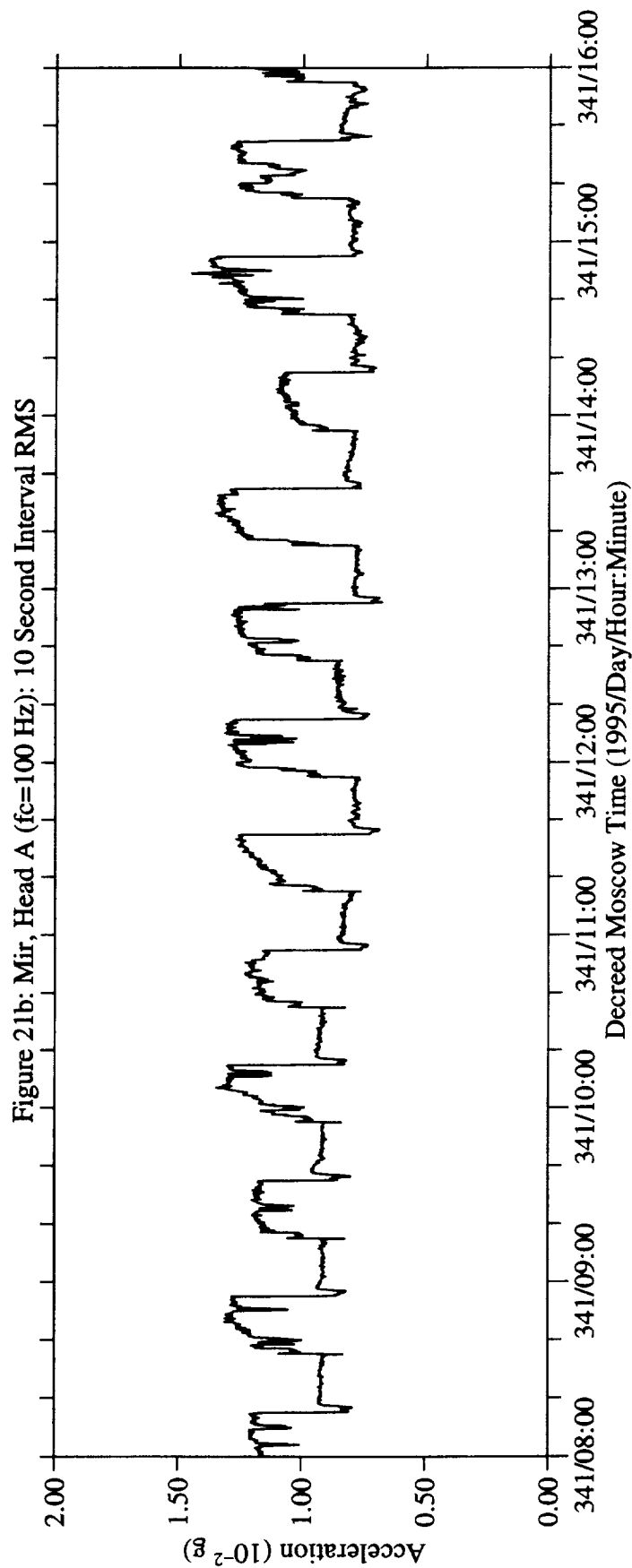
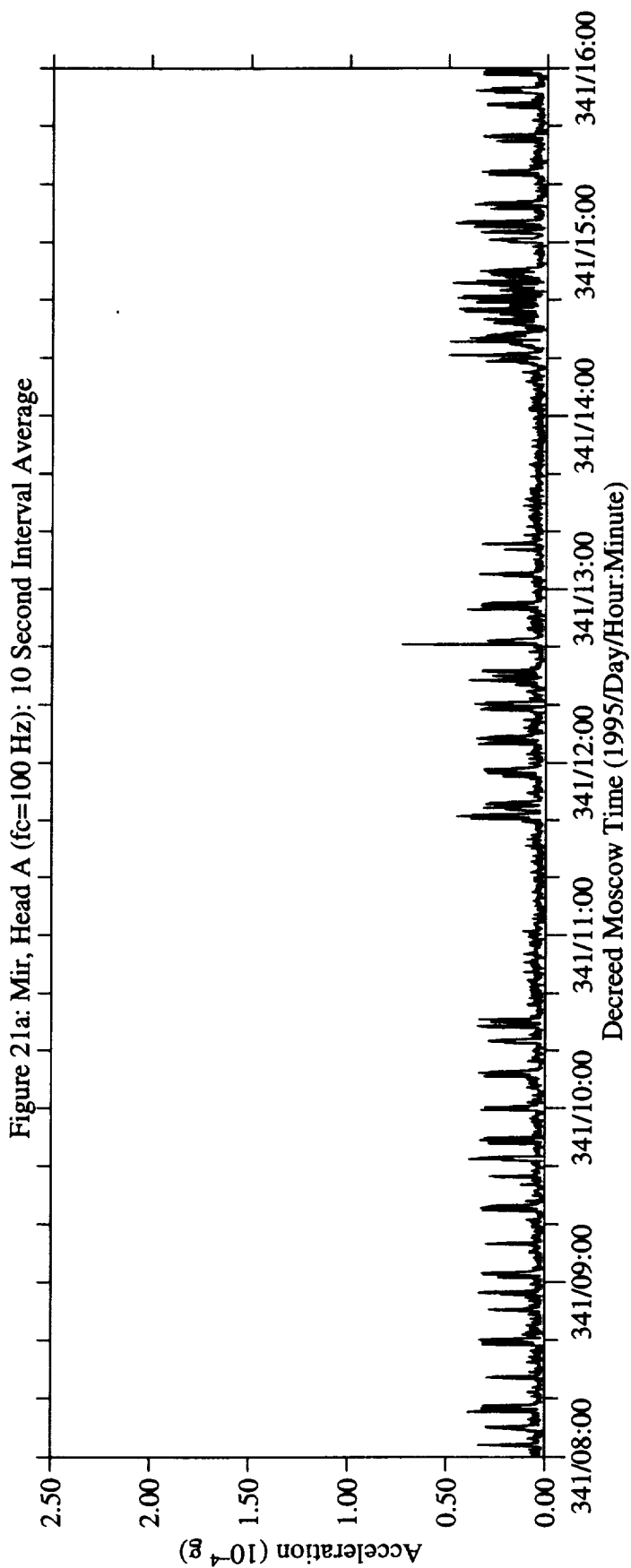
Figure 17b: Mir, Head A (fc=100 Hz): 10 Second Interval RMS











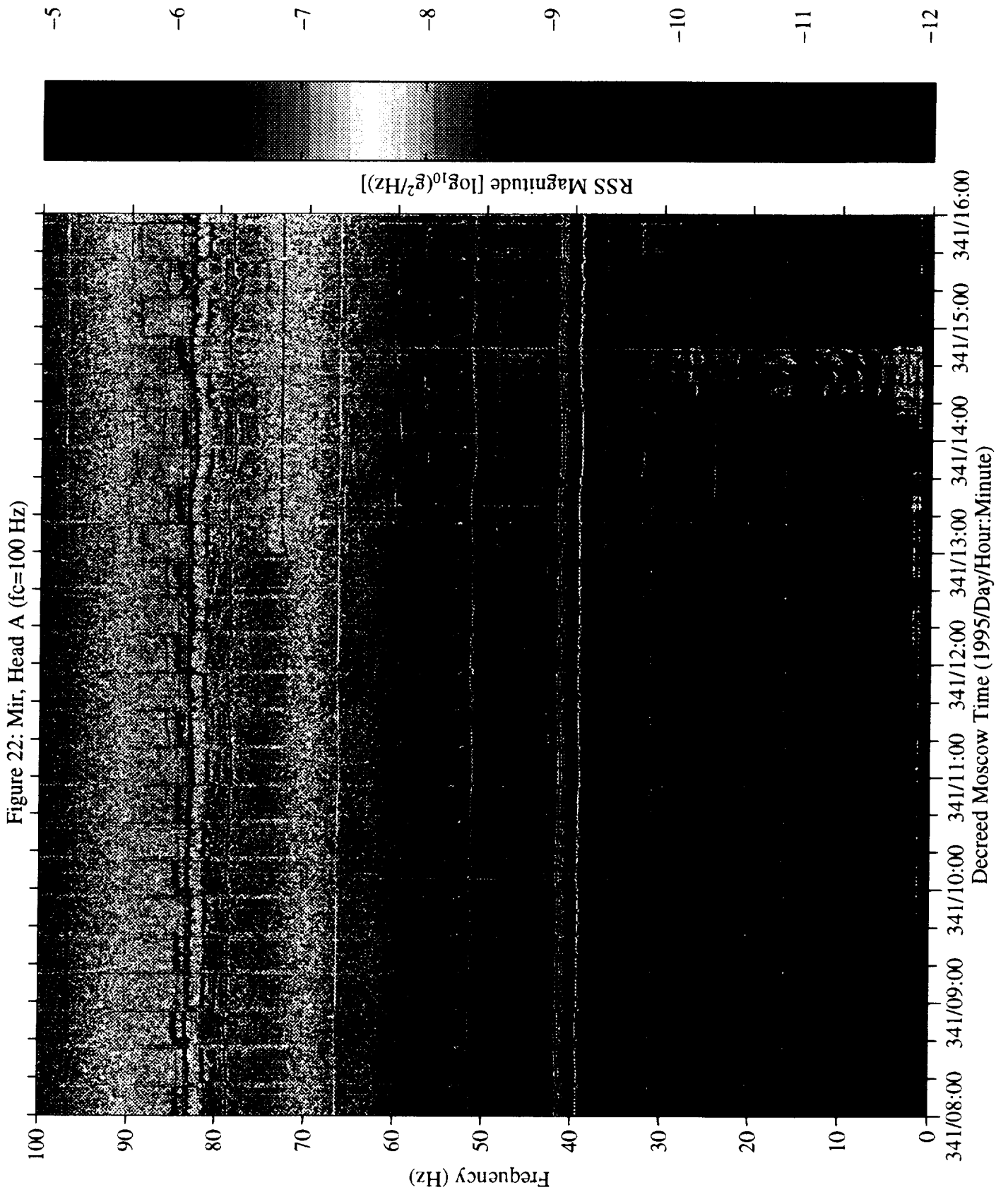


Figure 23a: Mir, Head A (fc=100 Hz): 10 Second Interval Average

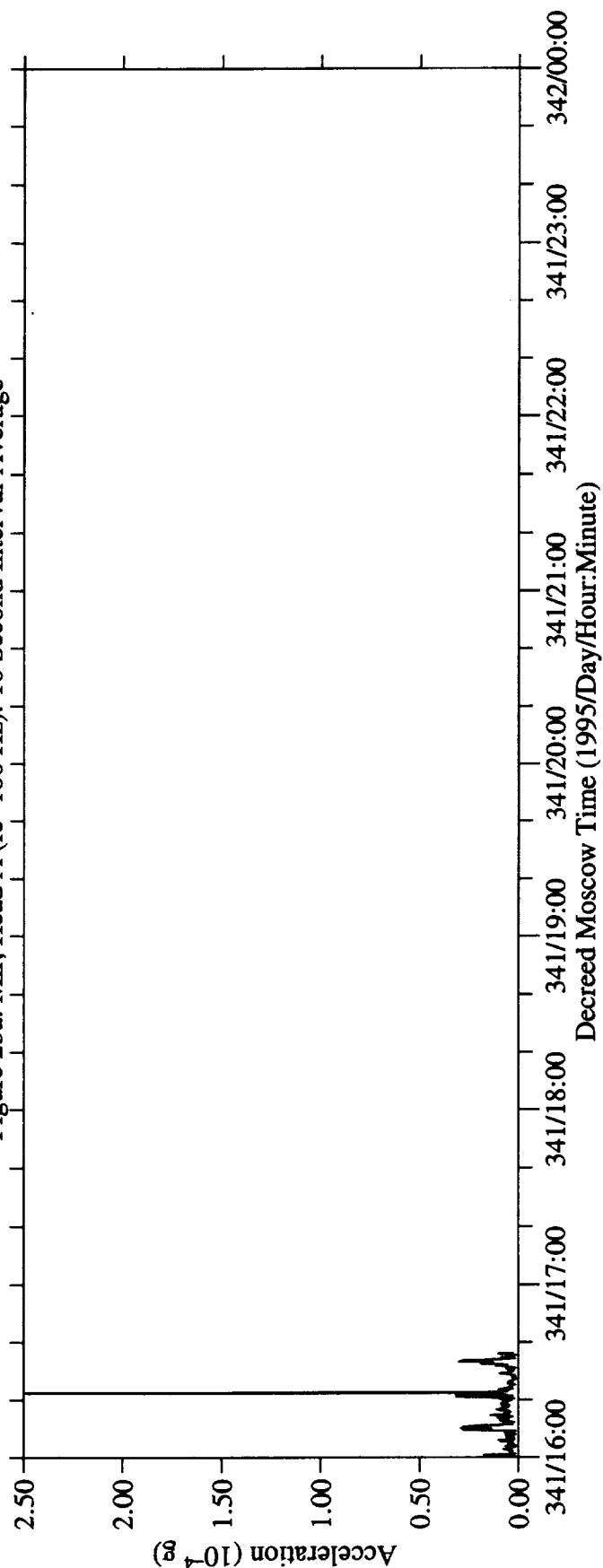
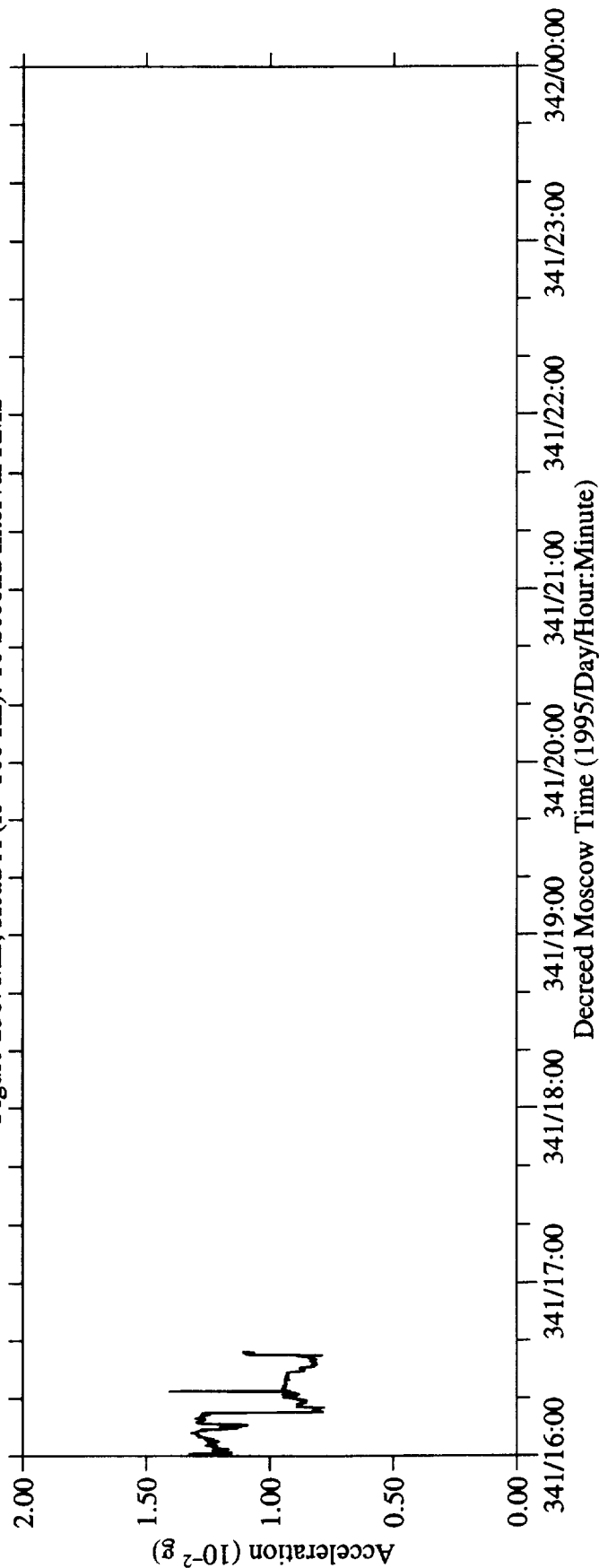
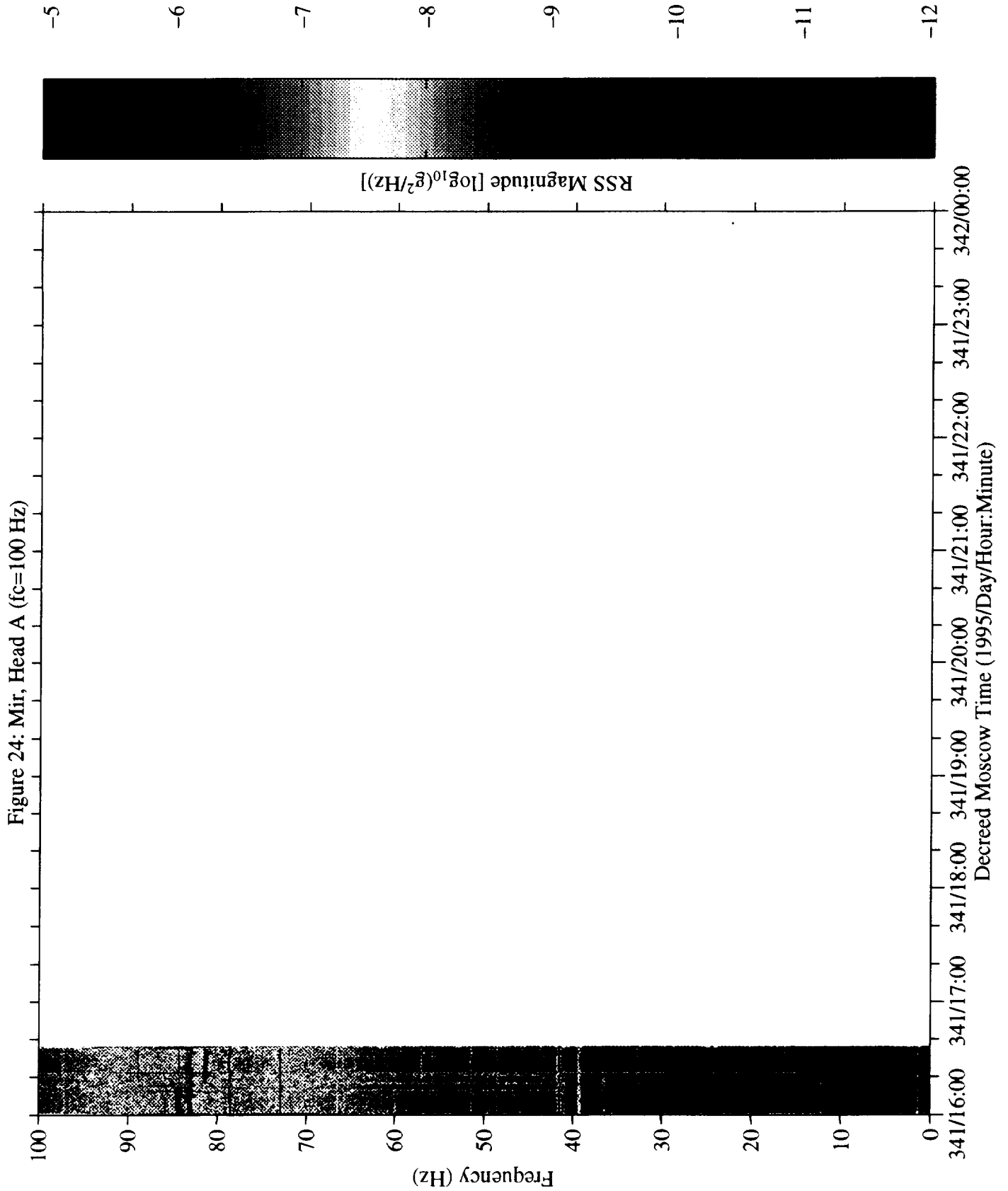


Figure 23b: Mir, Head A (fc=100 Hz): 10 Second Interval RMS

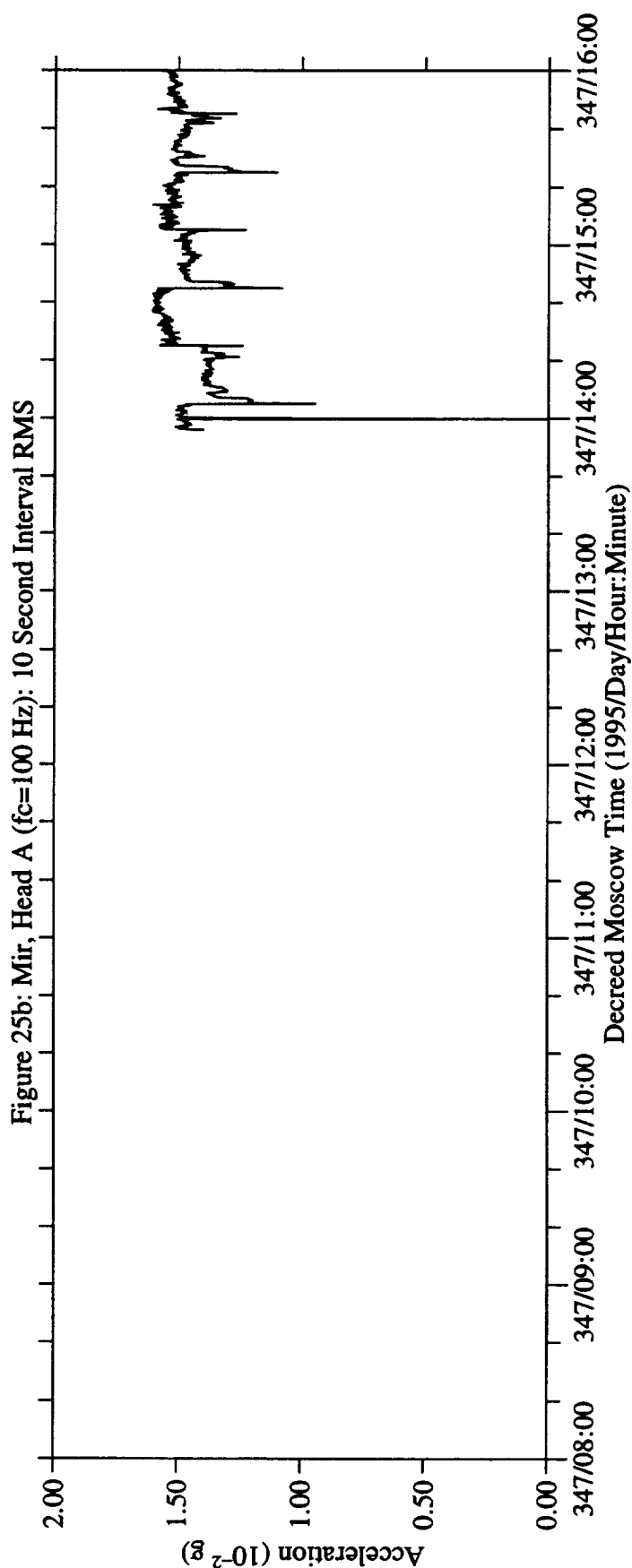
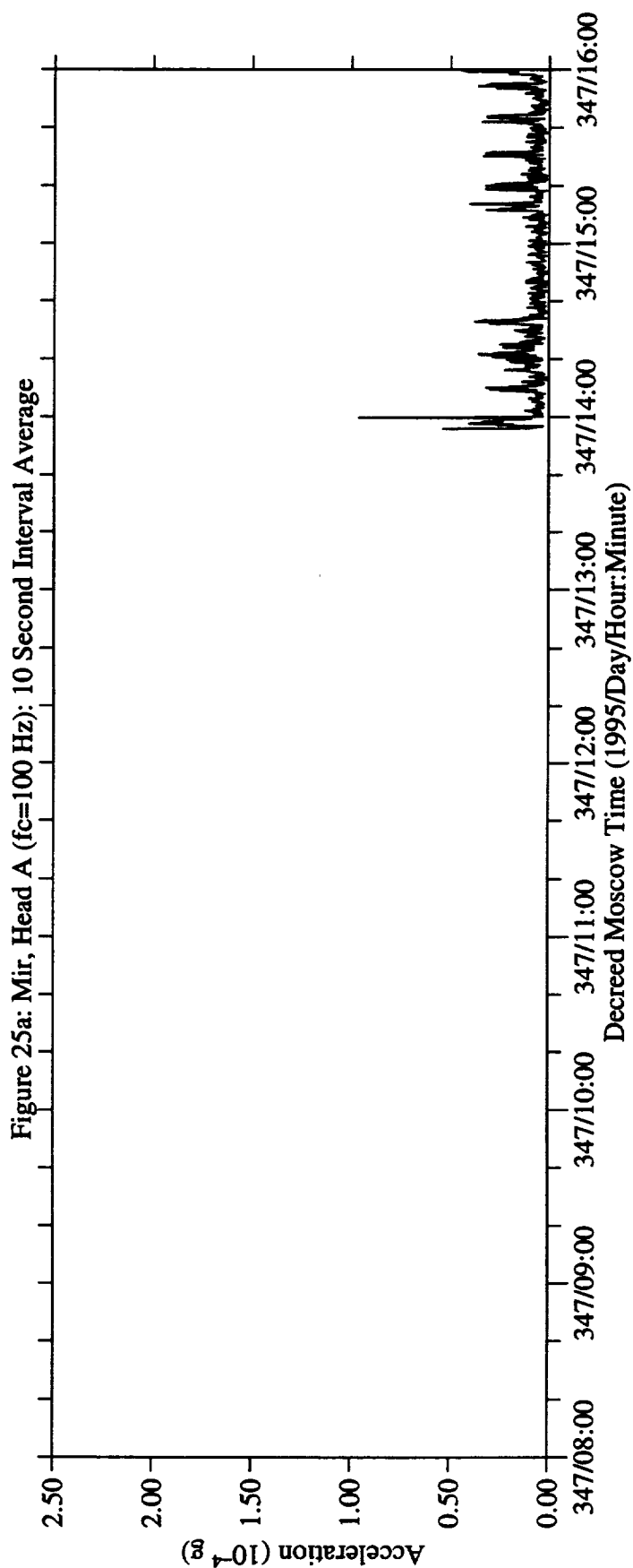


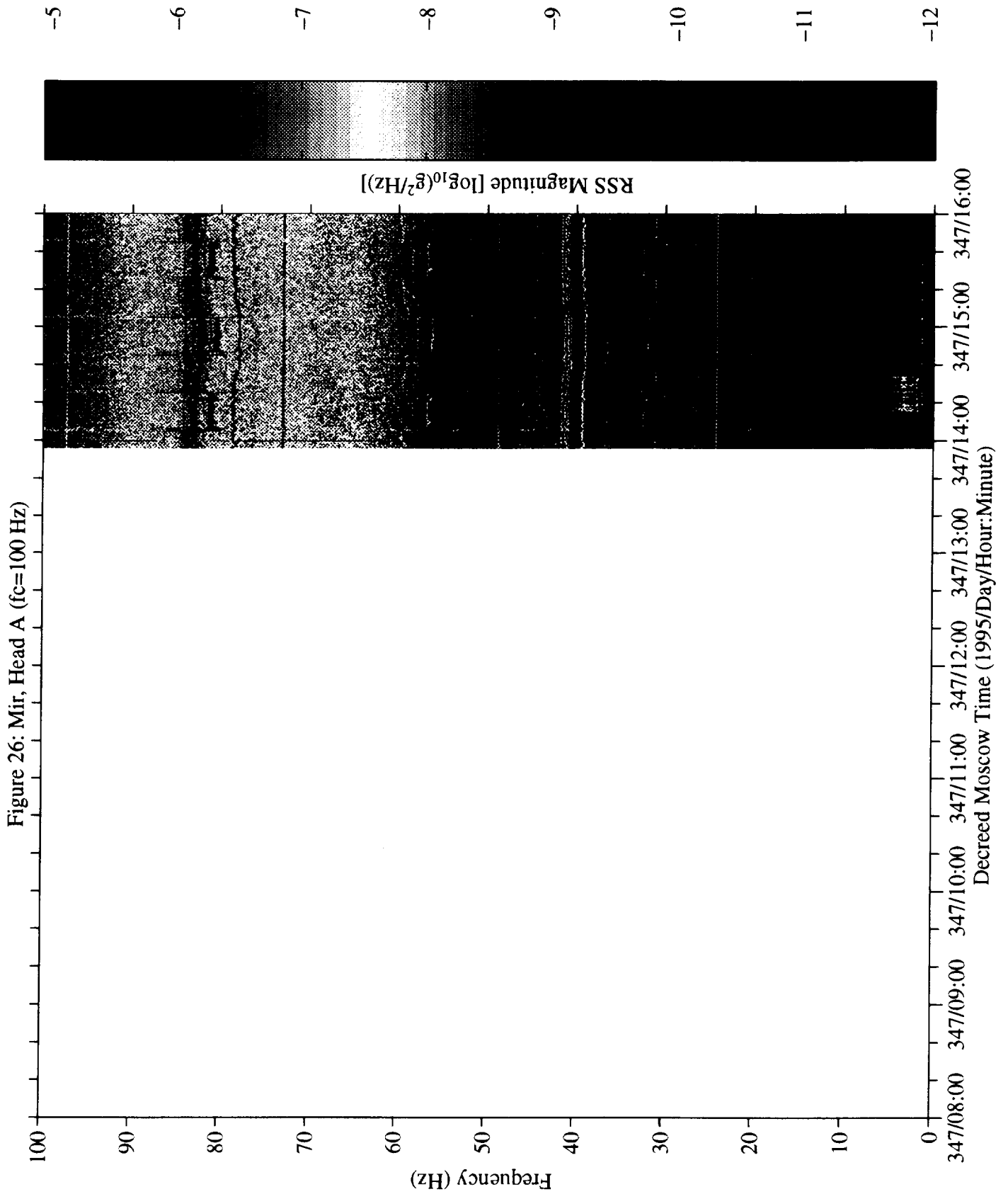


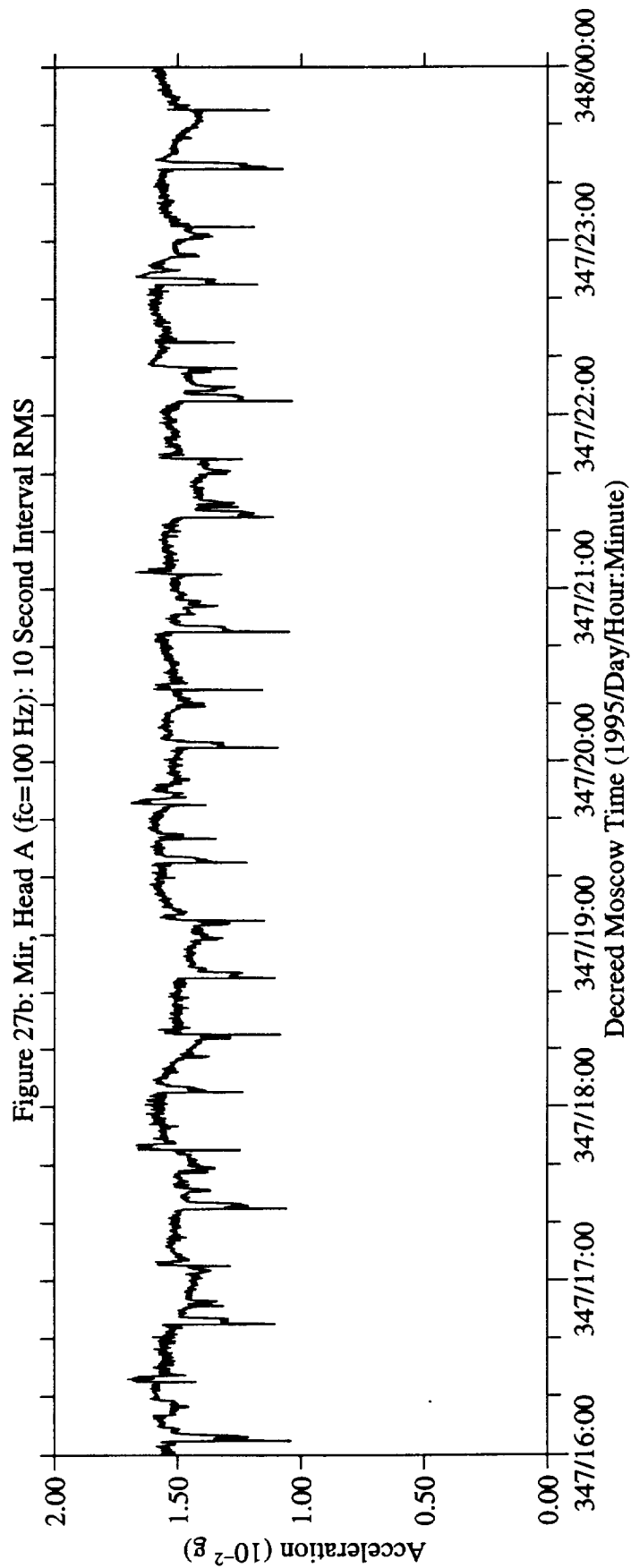
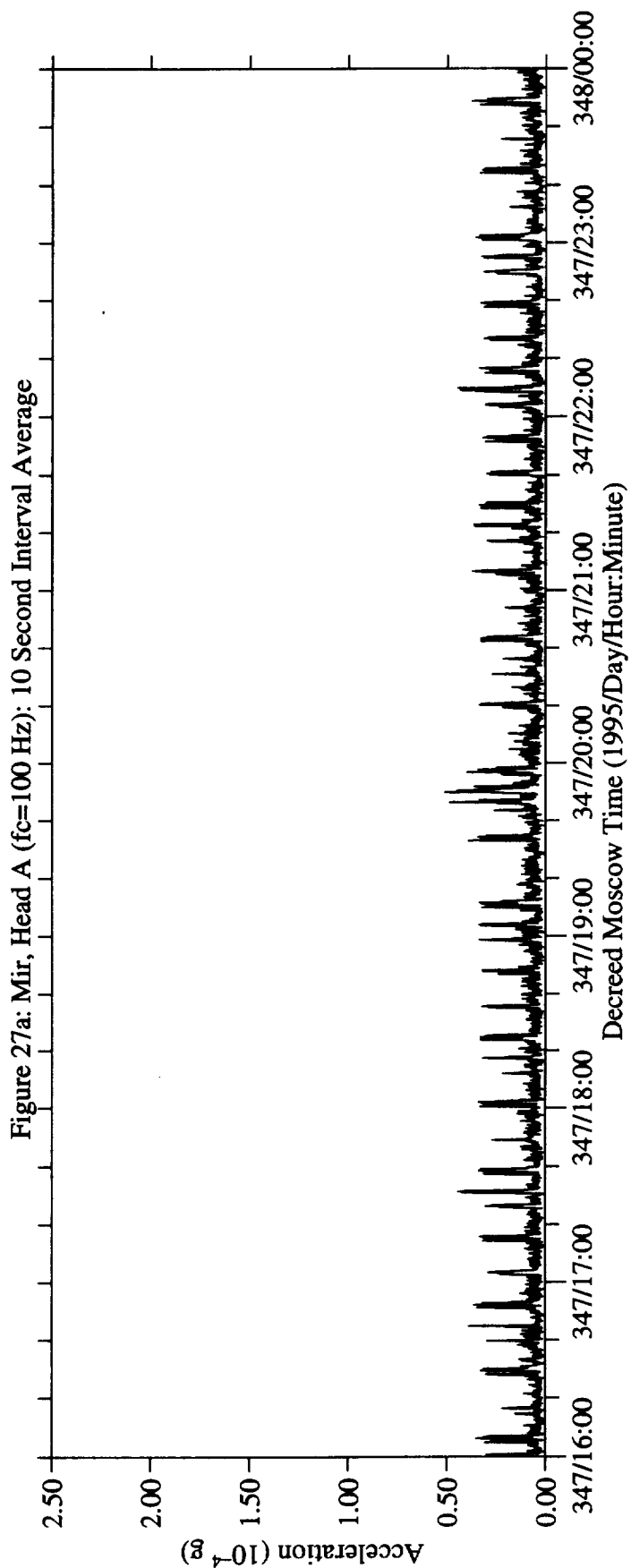


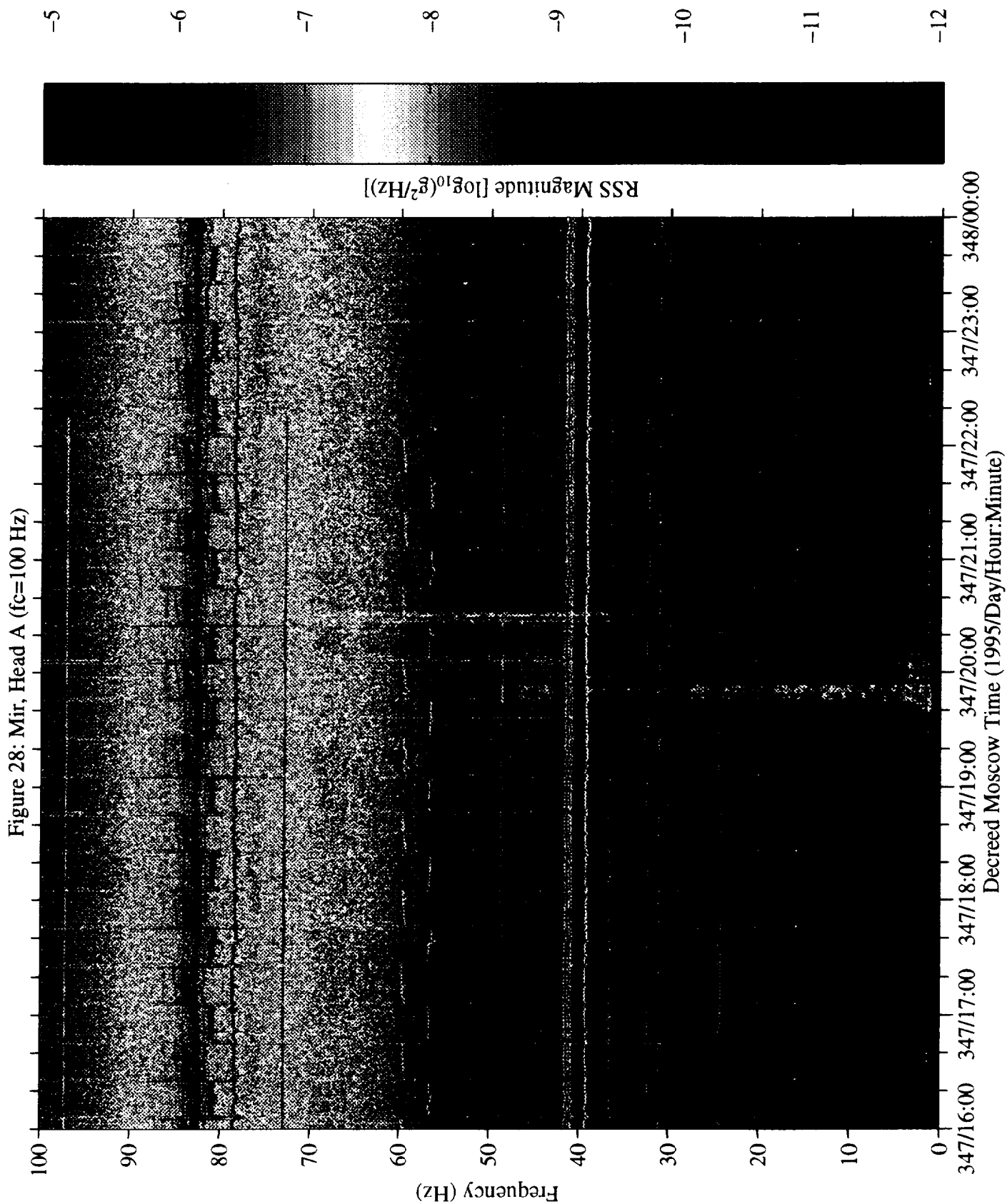
No data are available  
from 342/00:00:00 to 347/08:00:00

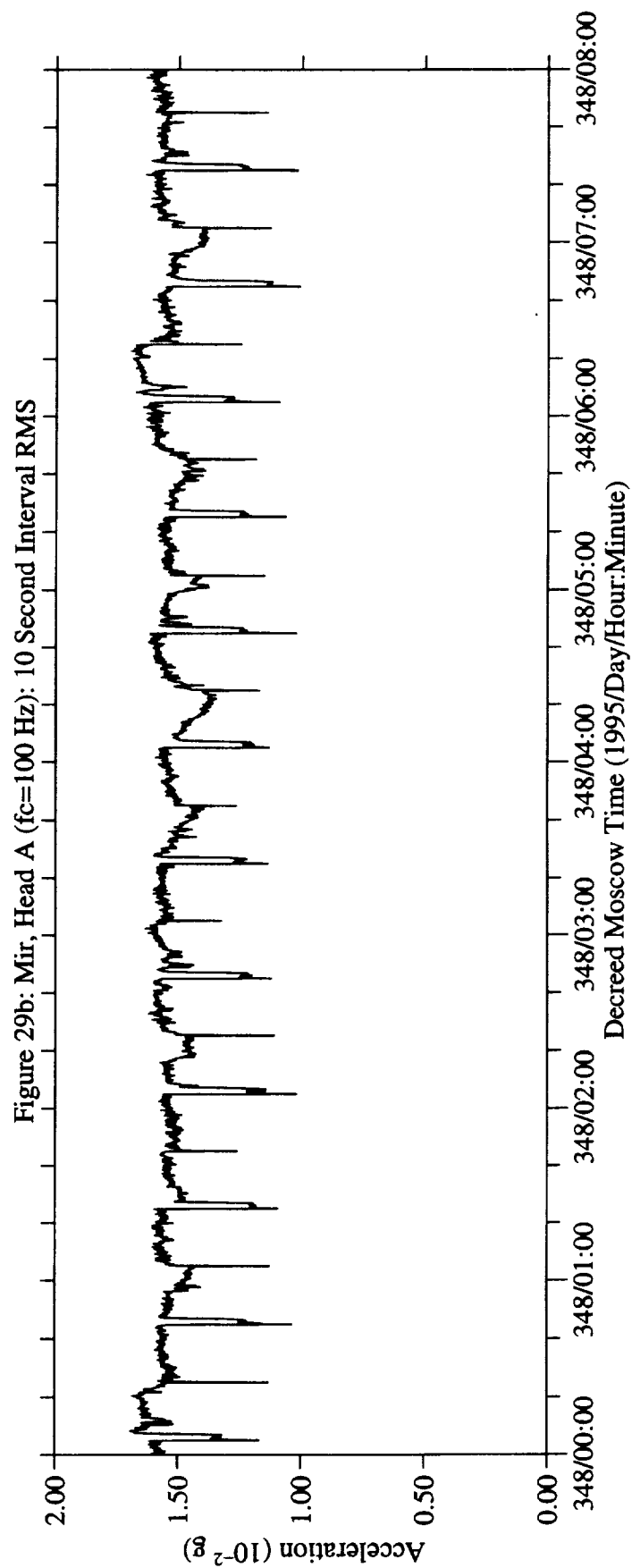
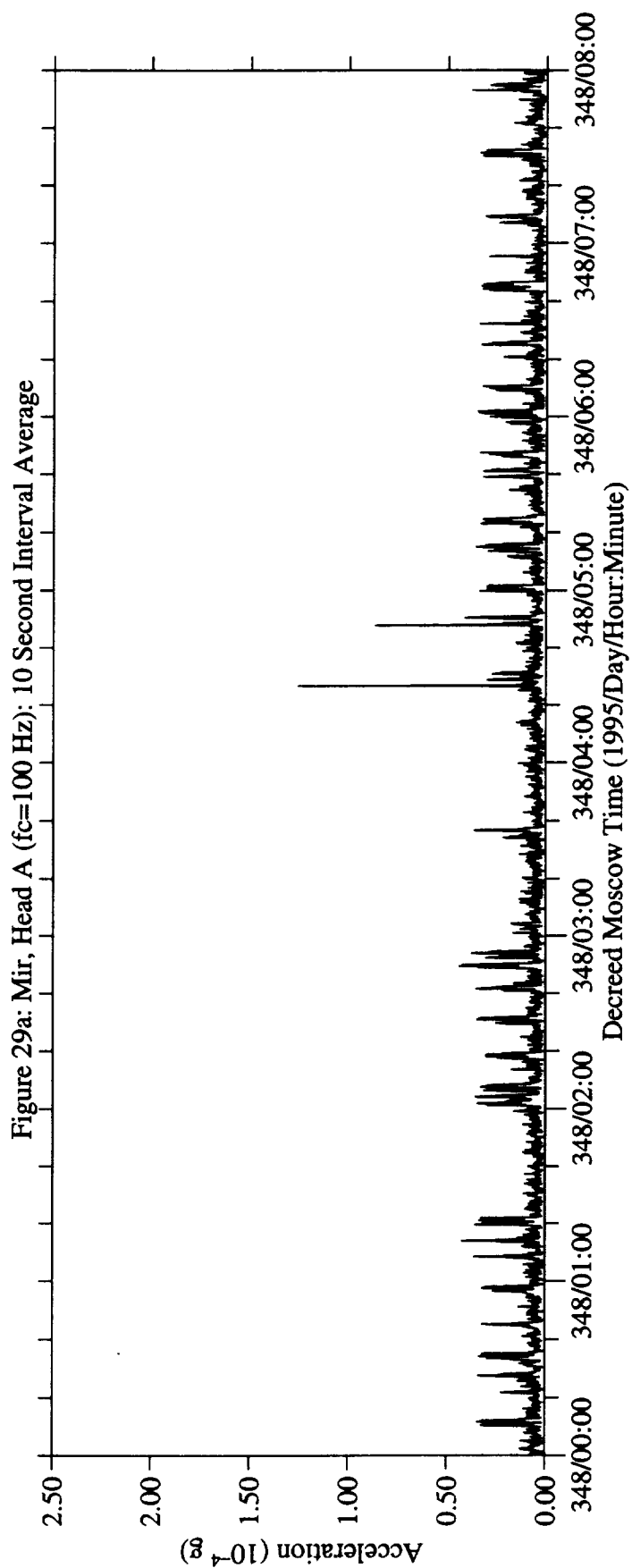
No data are available  
from 342/00:00:00 to 347/08:00:00



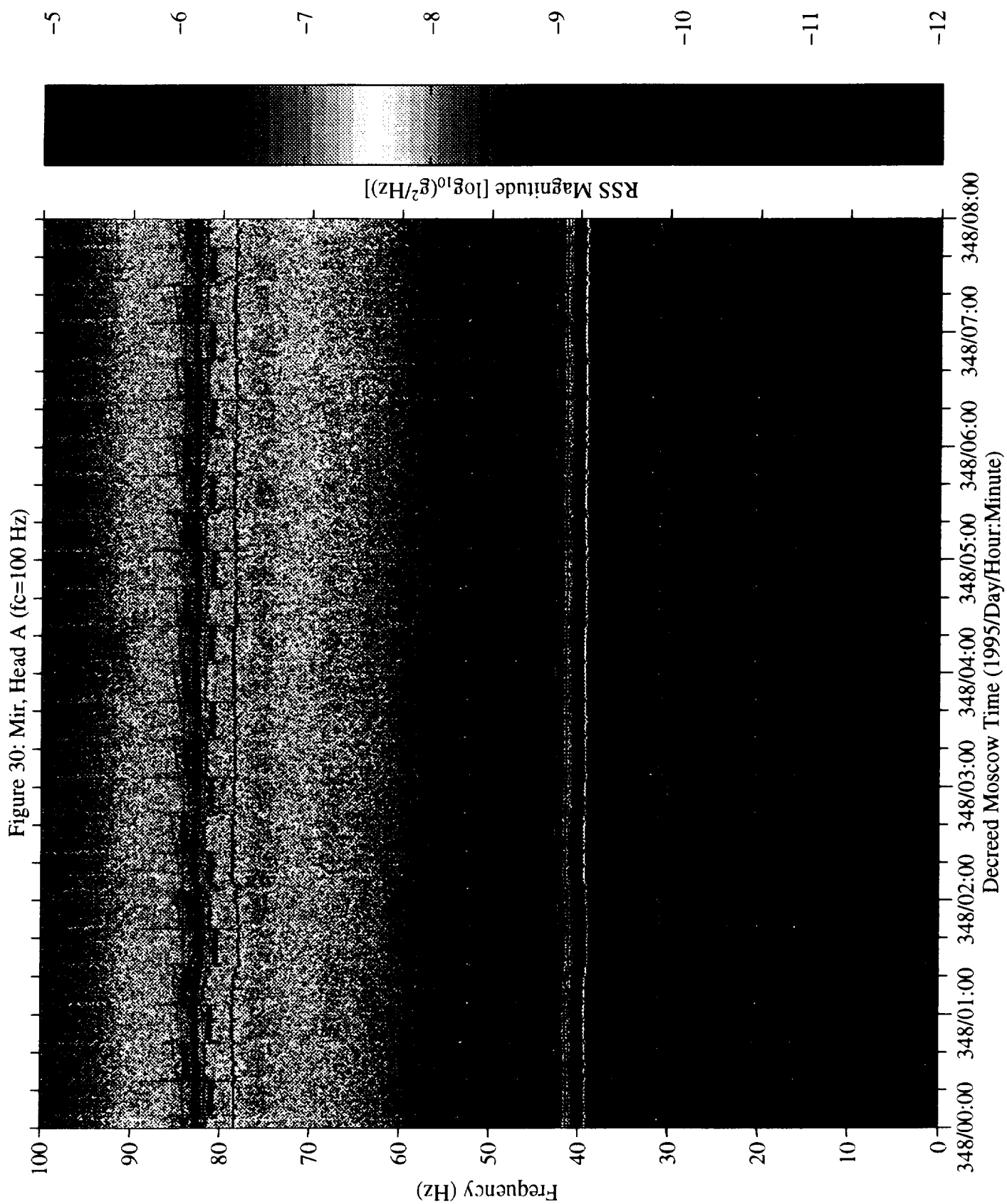


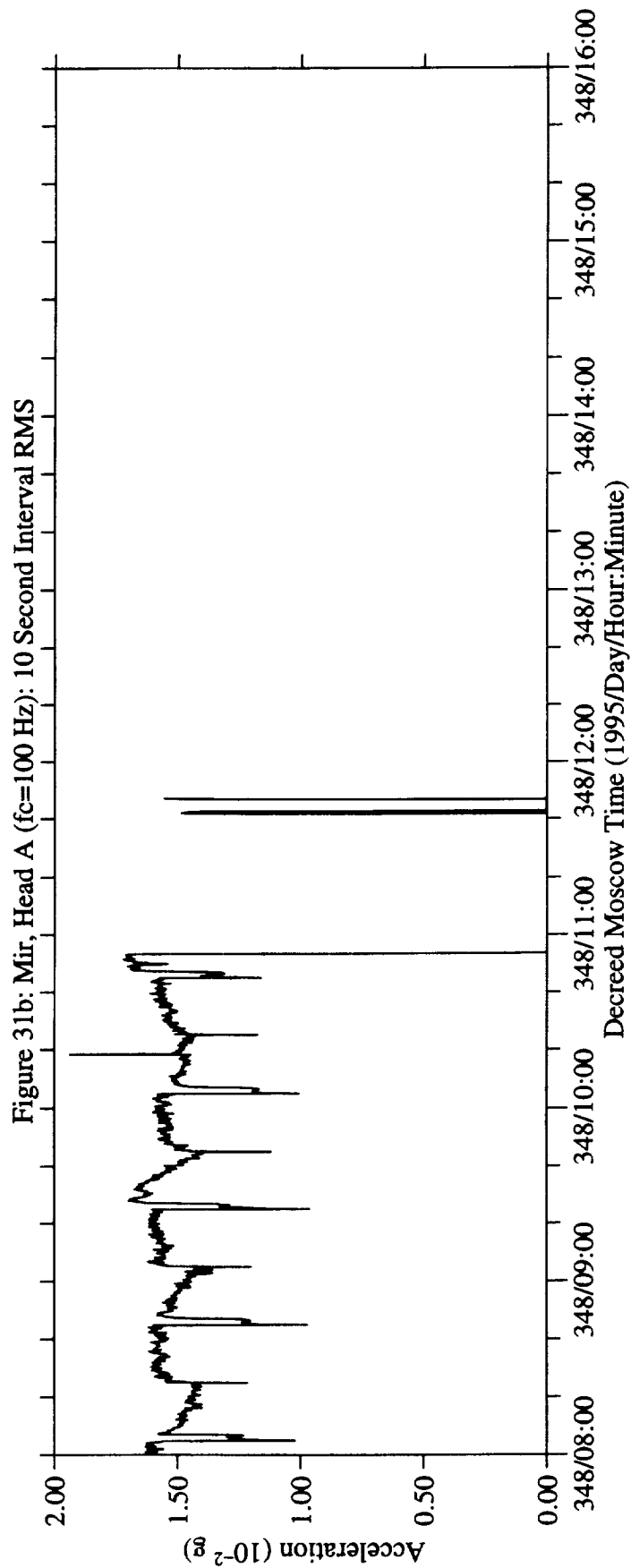
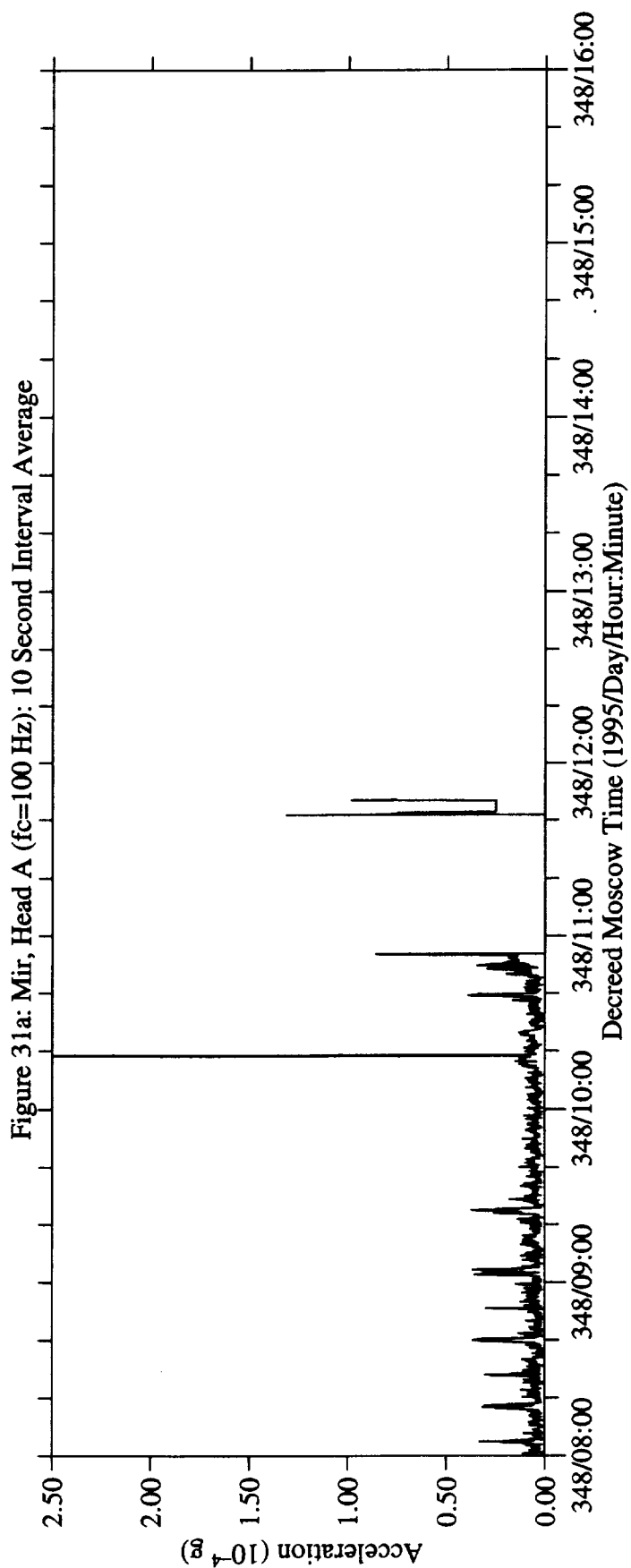


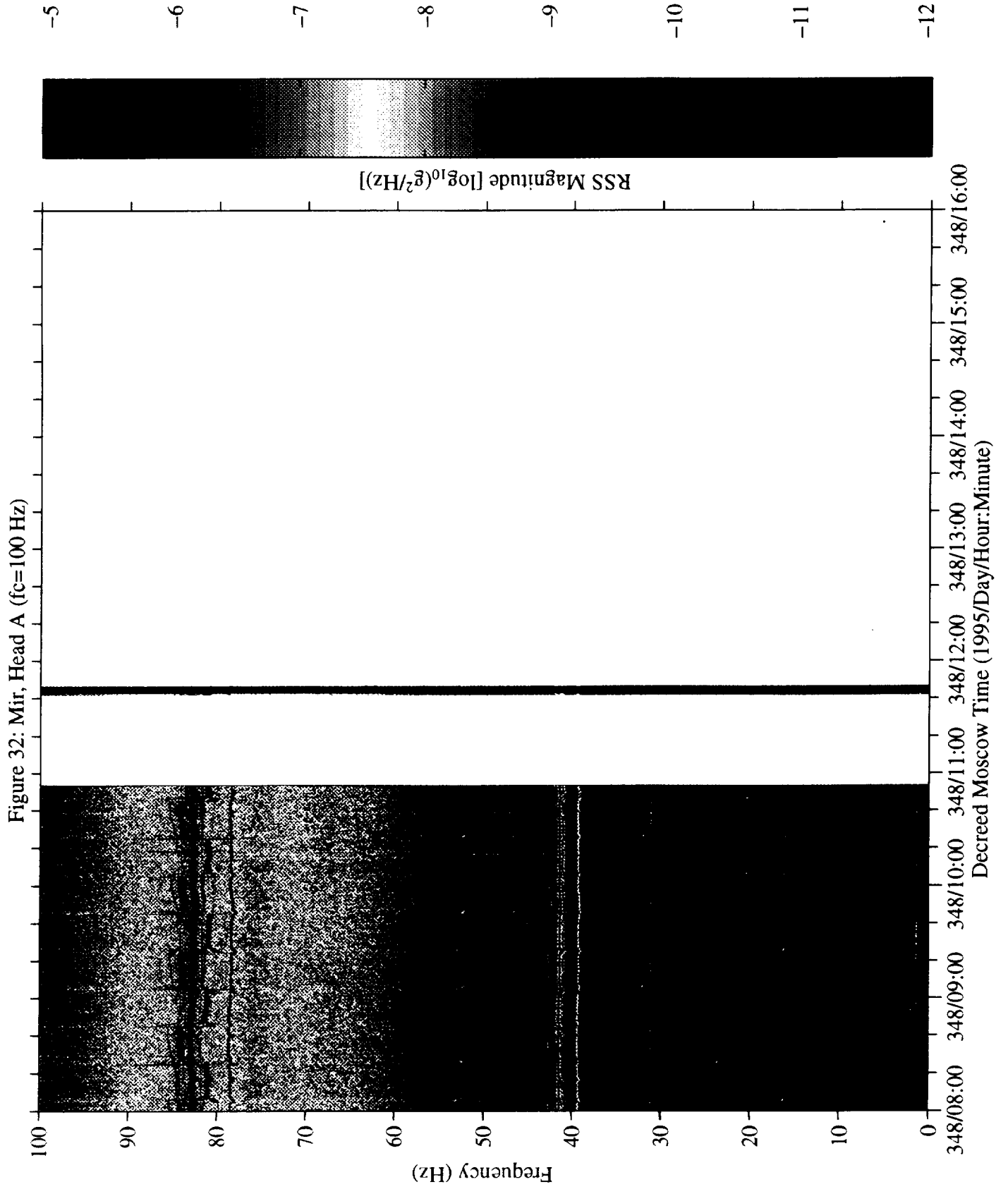






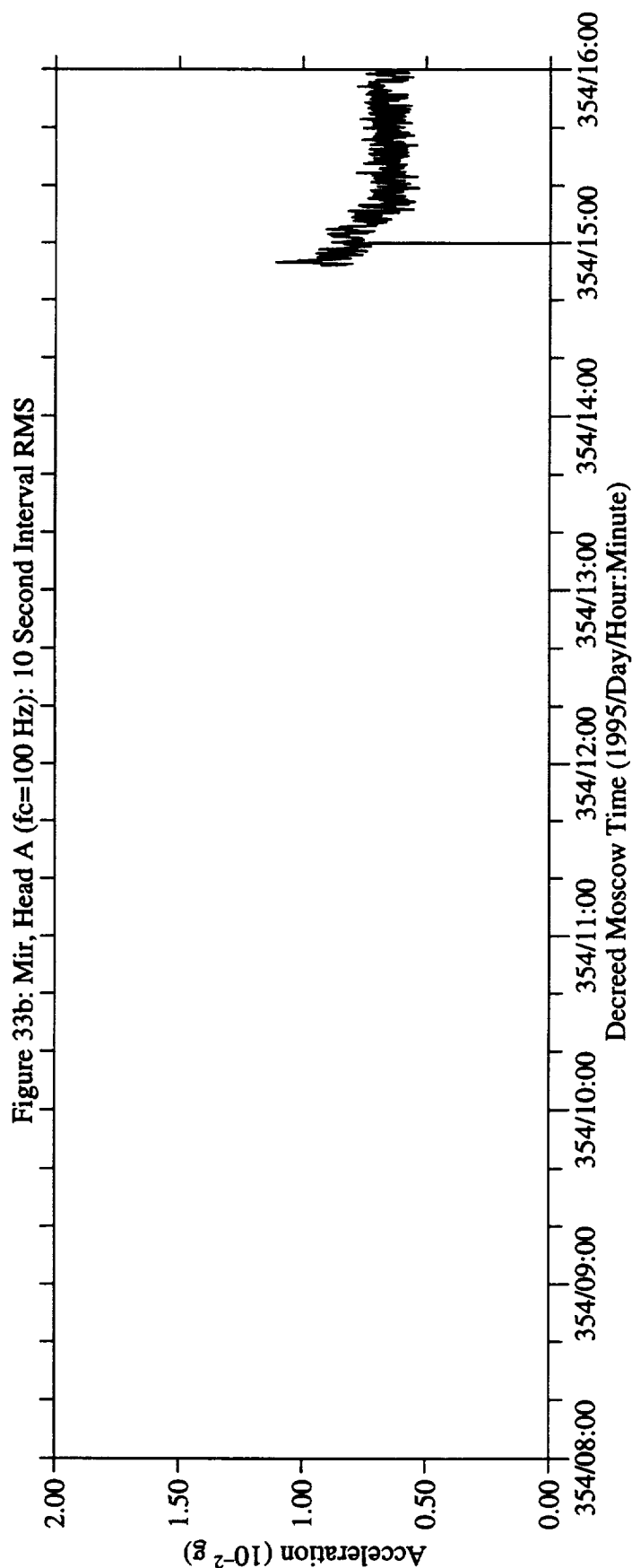
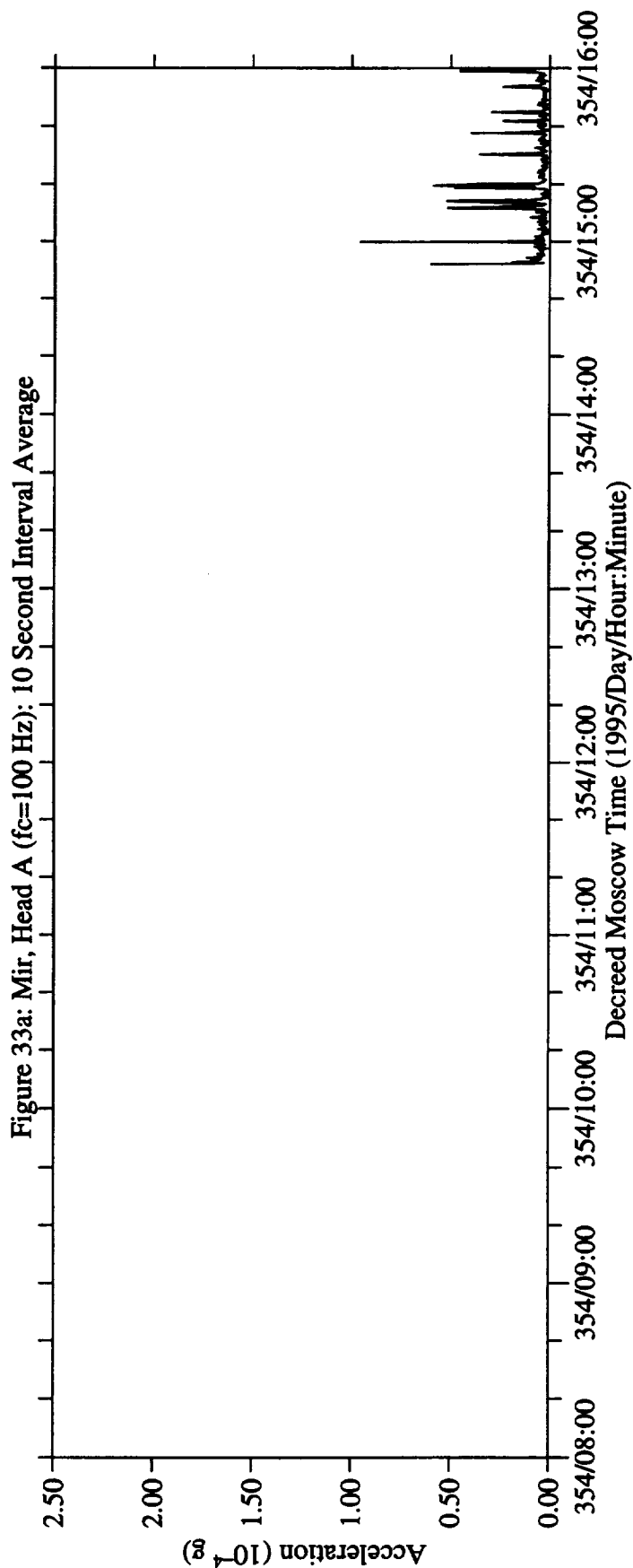


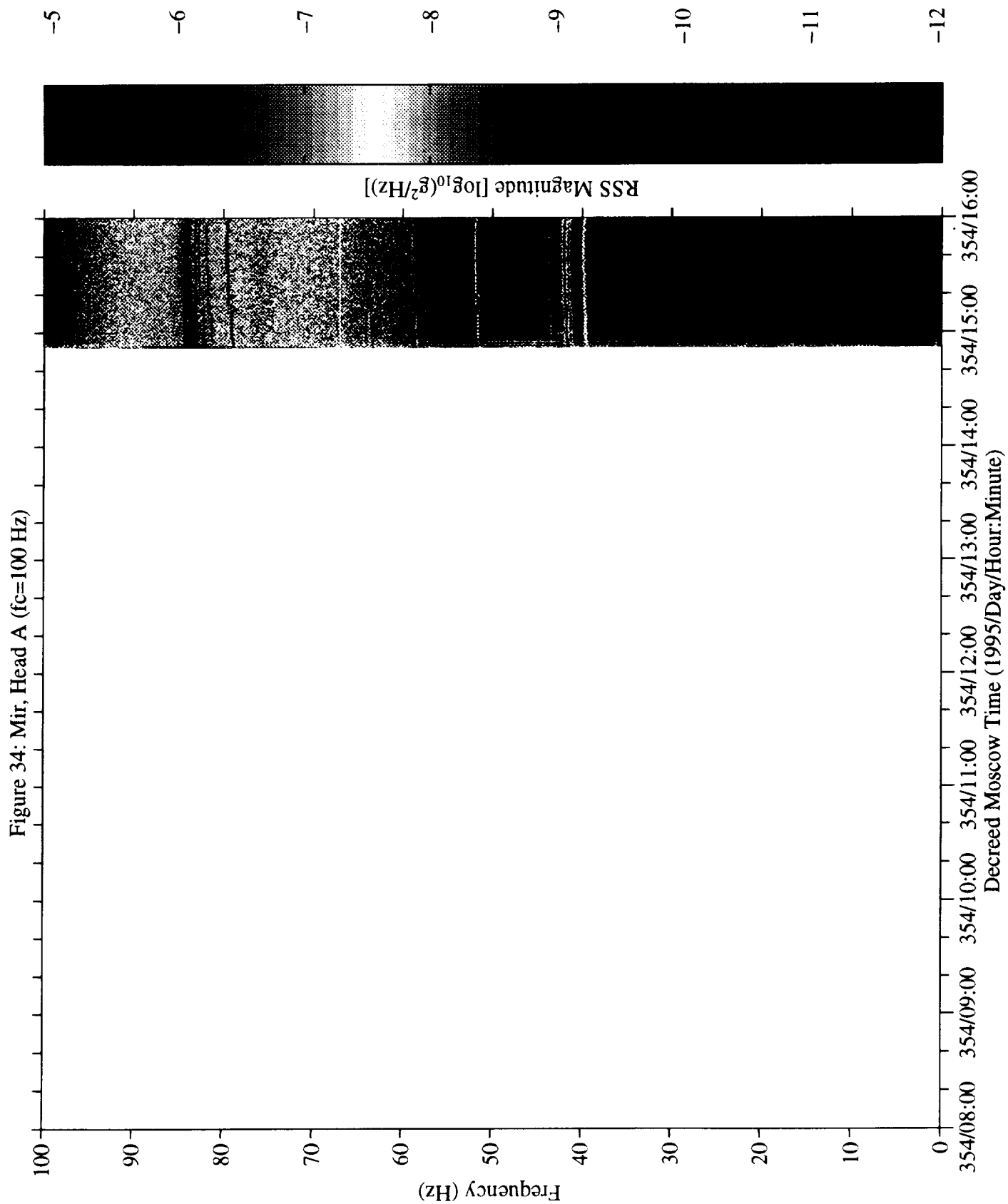


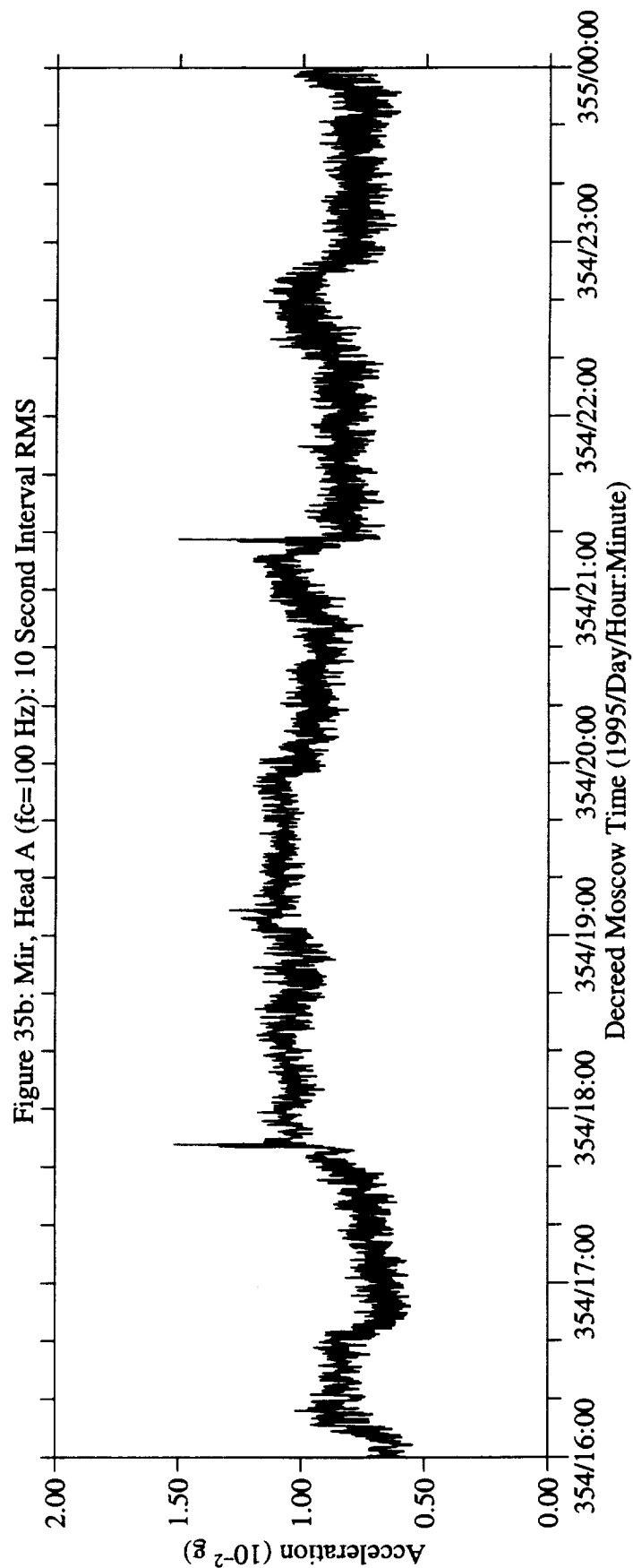
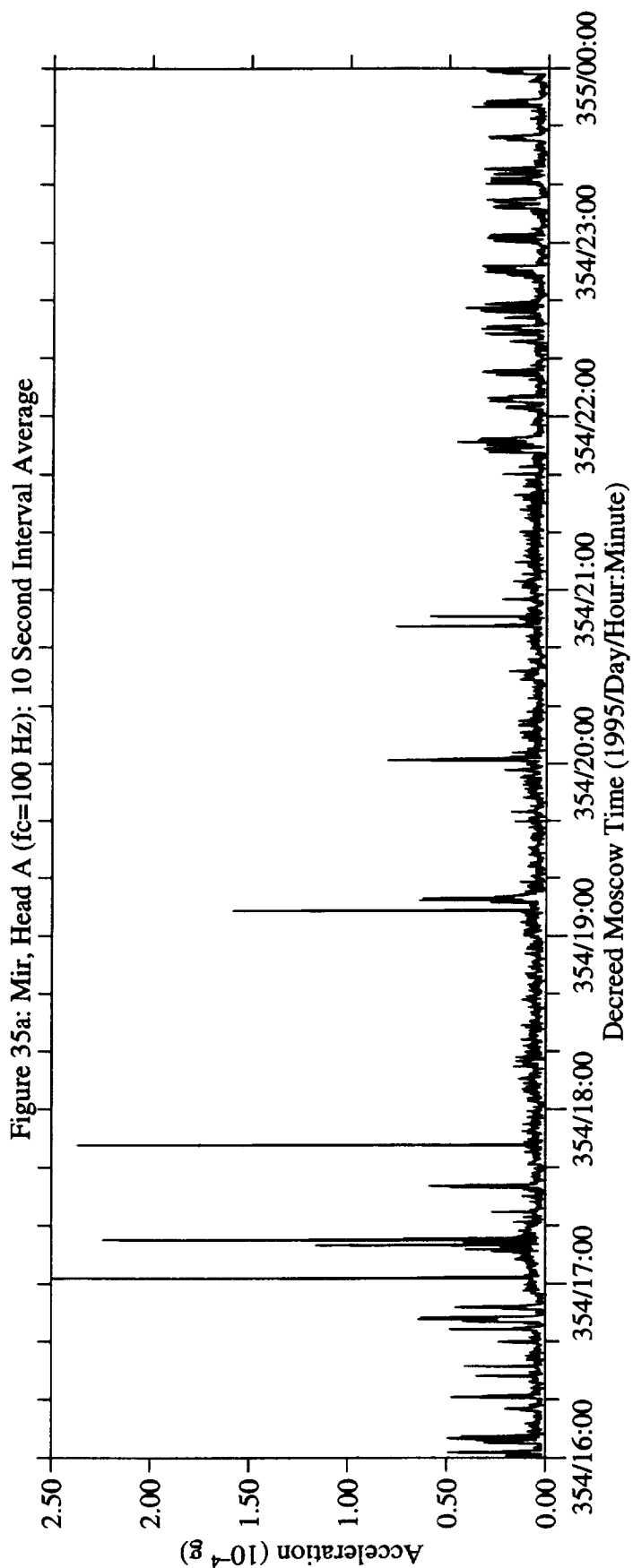


No data are available  
from 348/16:00:00 to 354/08:00:00

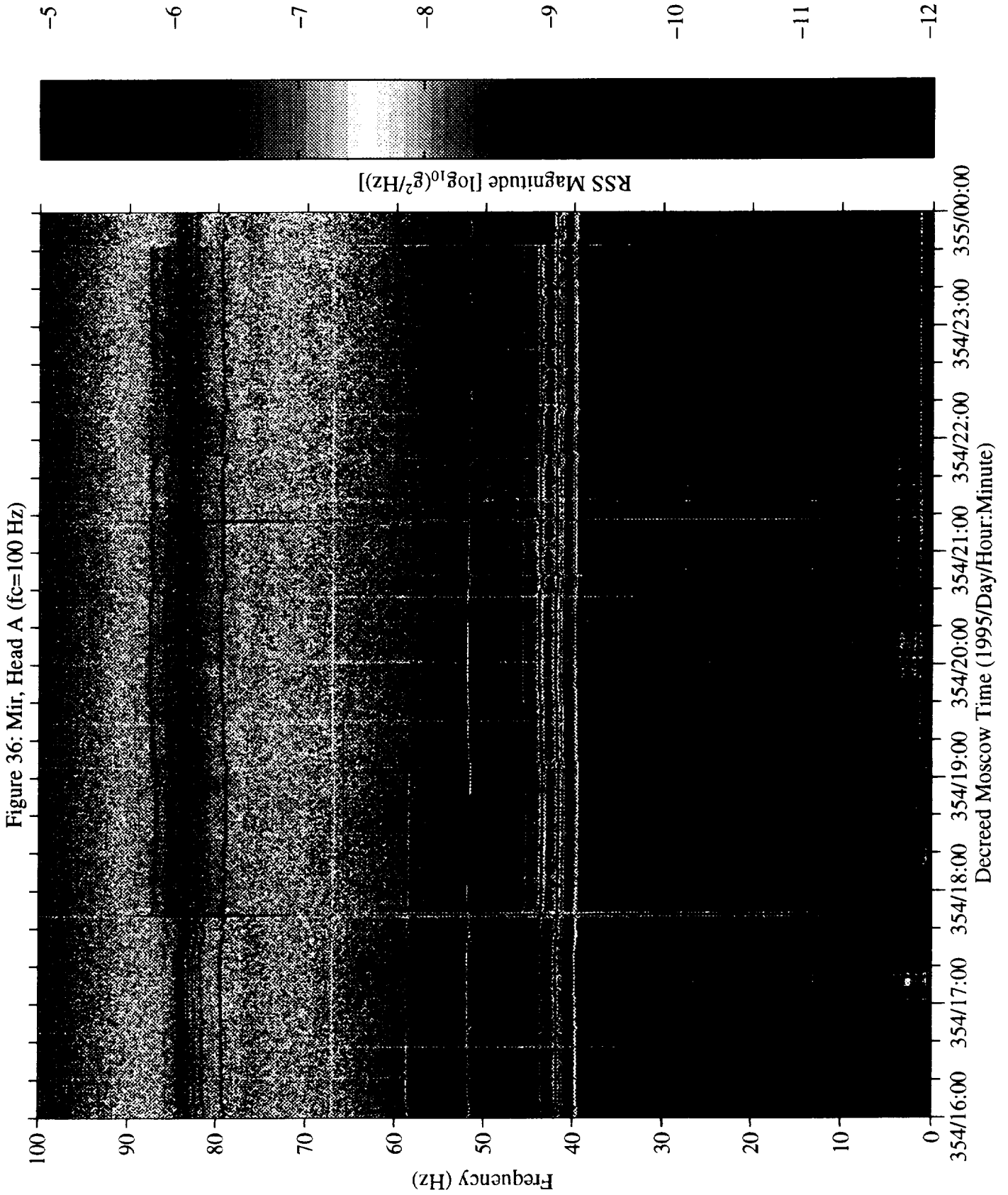
No data are available  
from 348/16:00:00 to 354/08:00:00

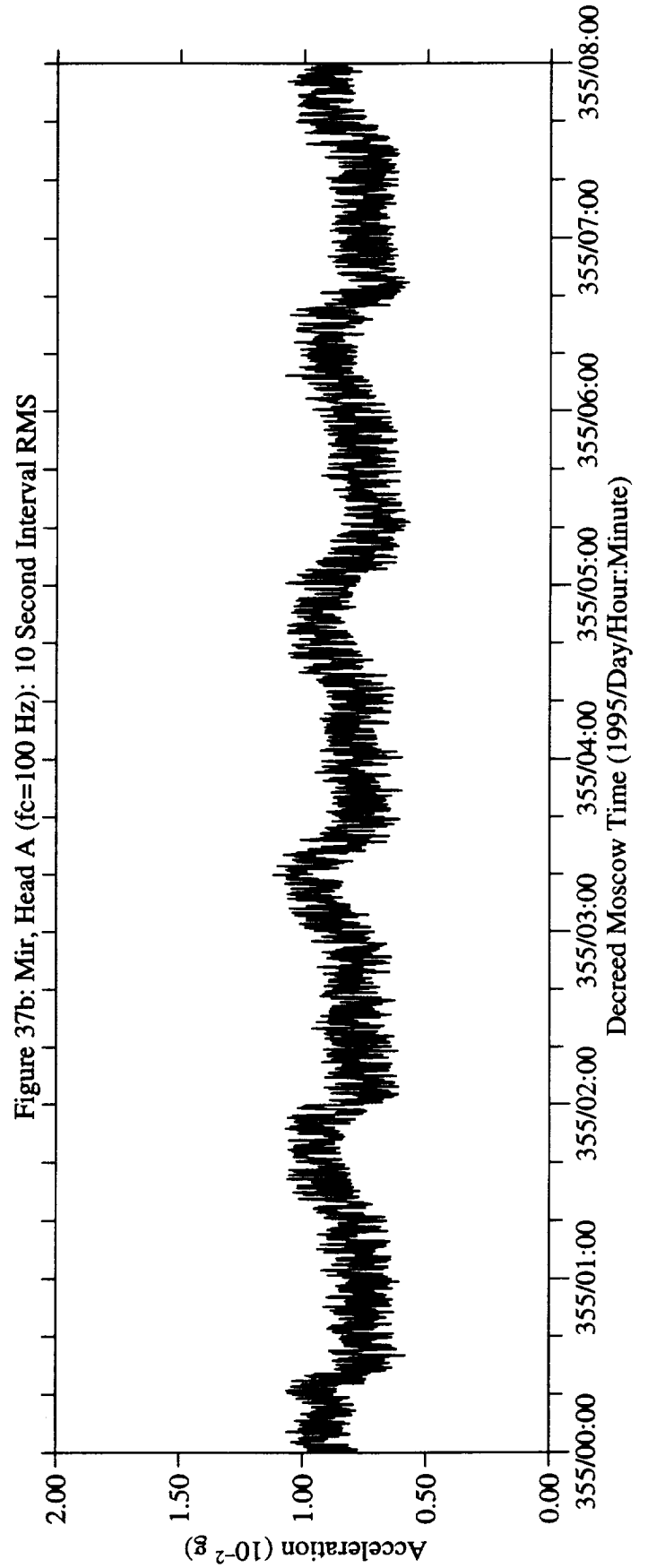
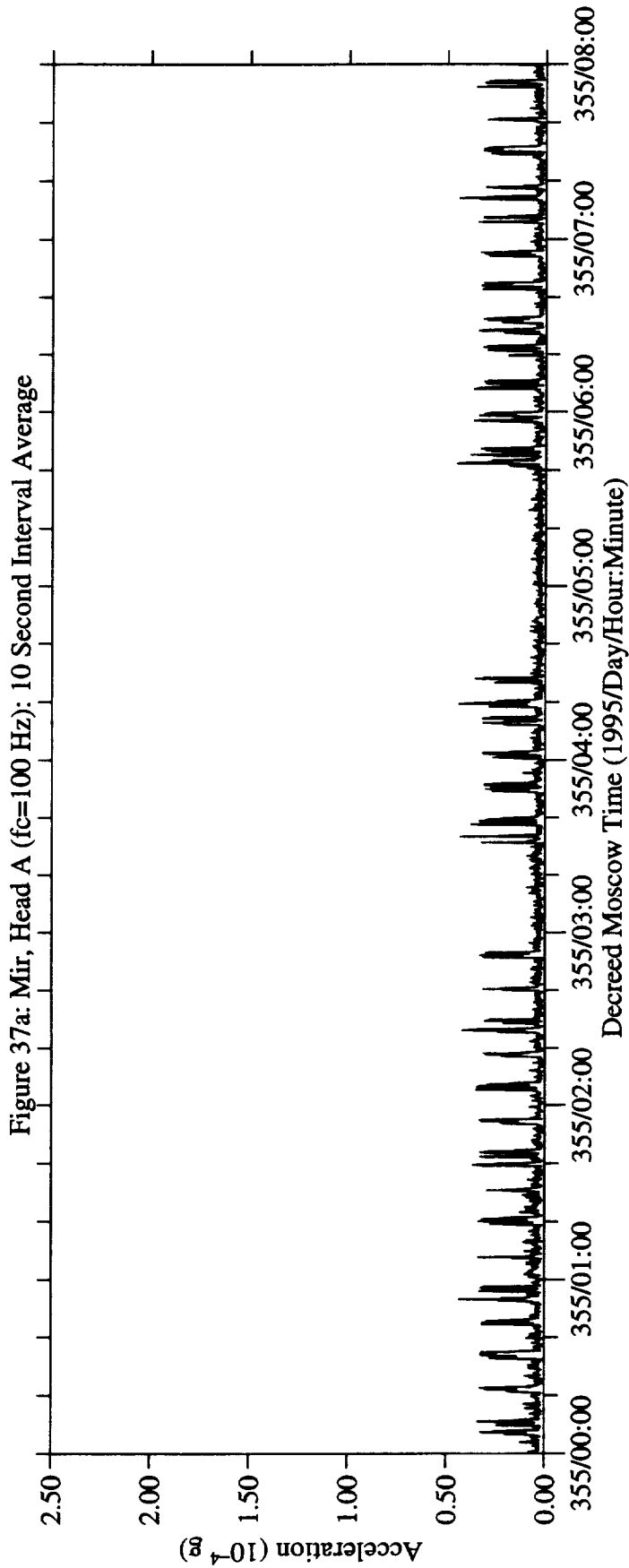


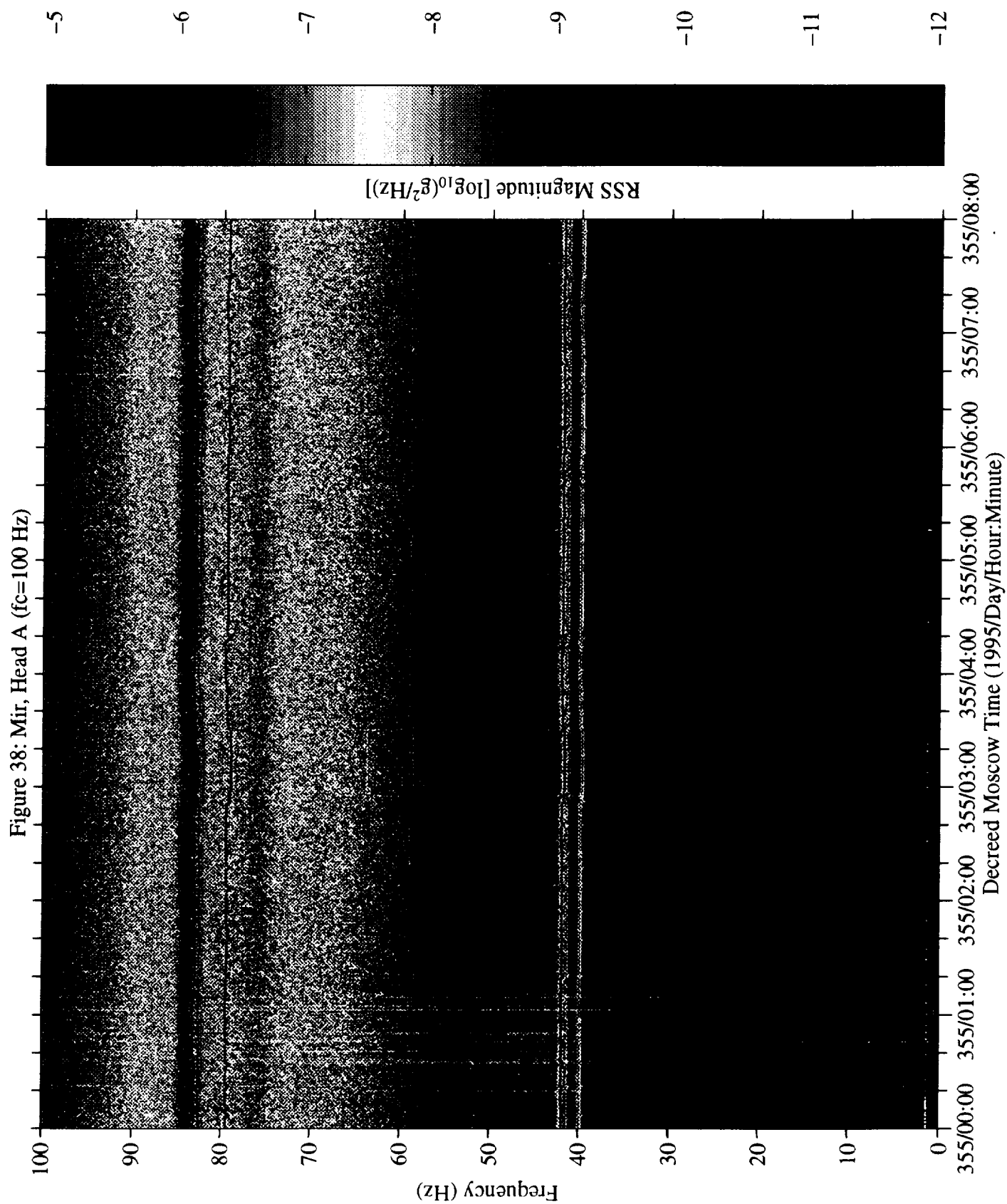


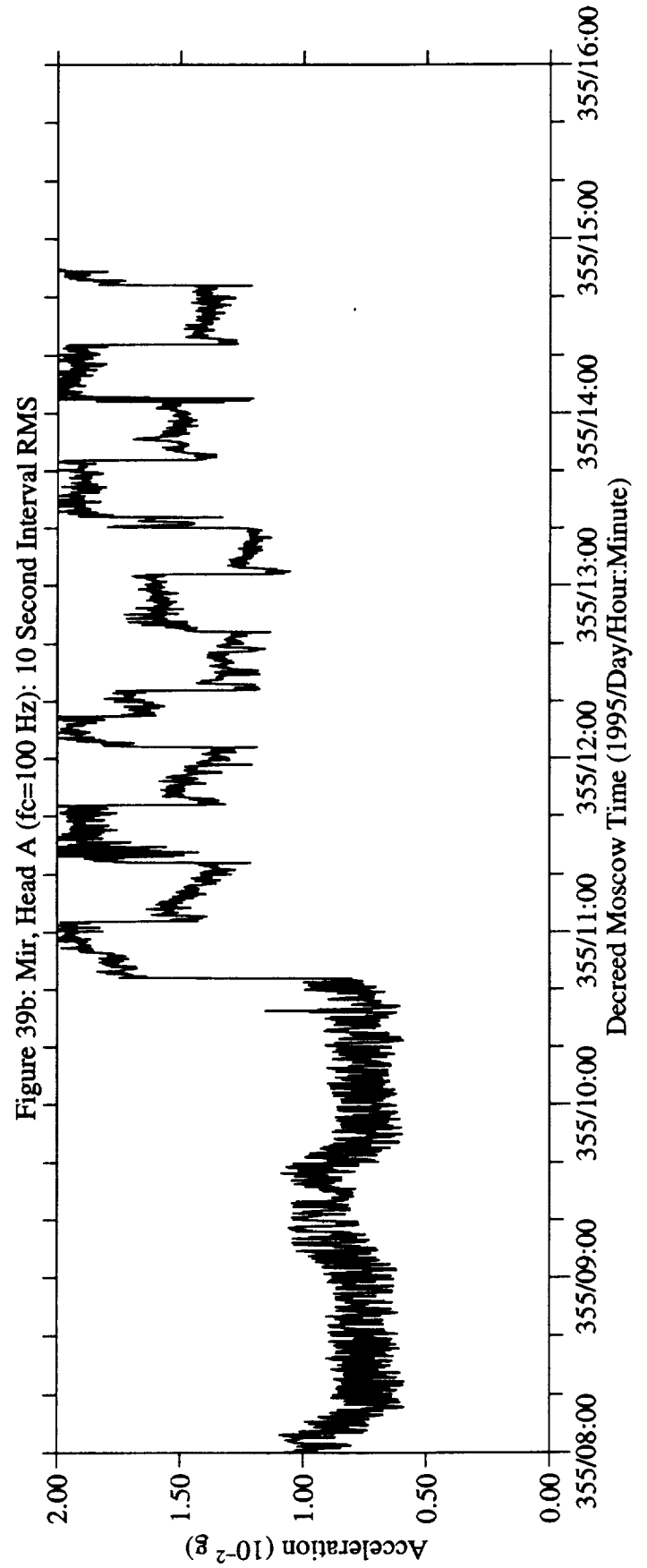
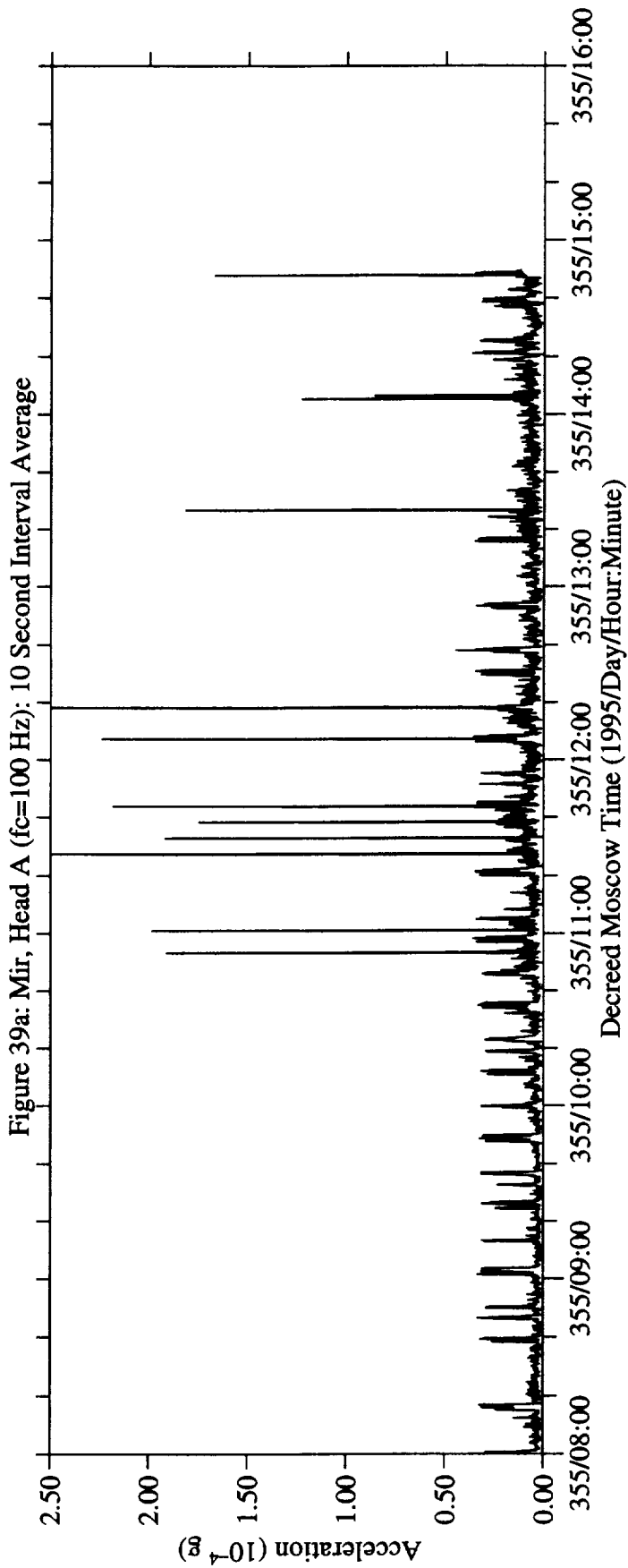


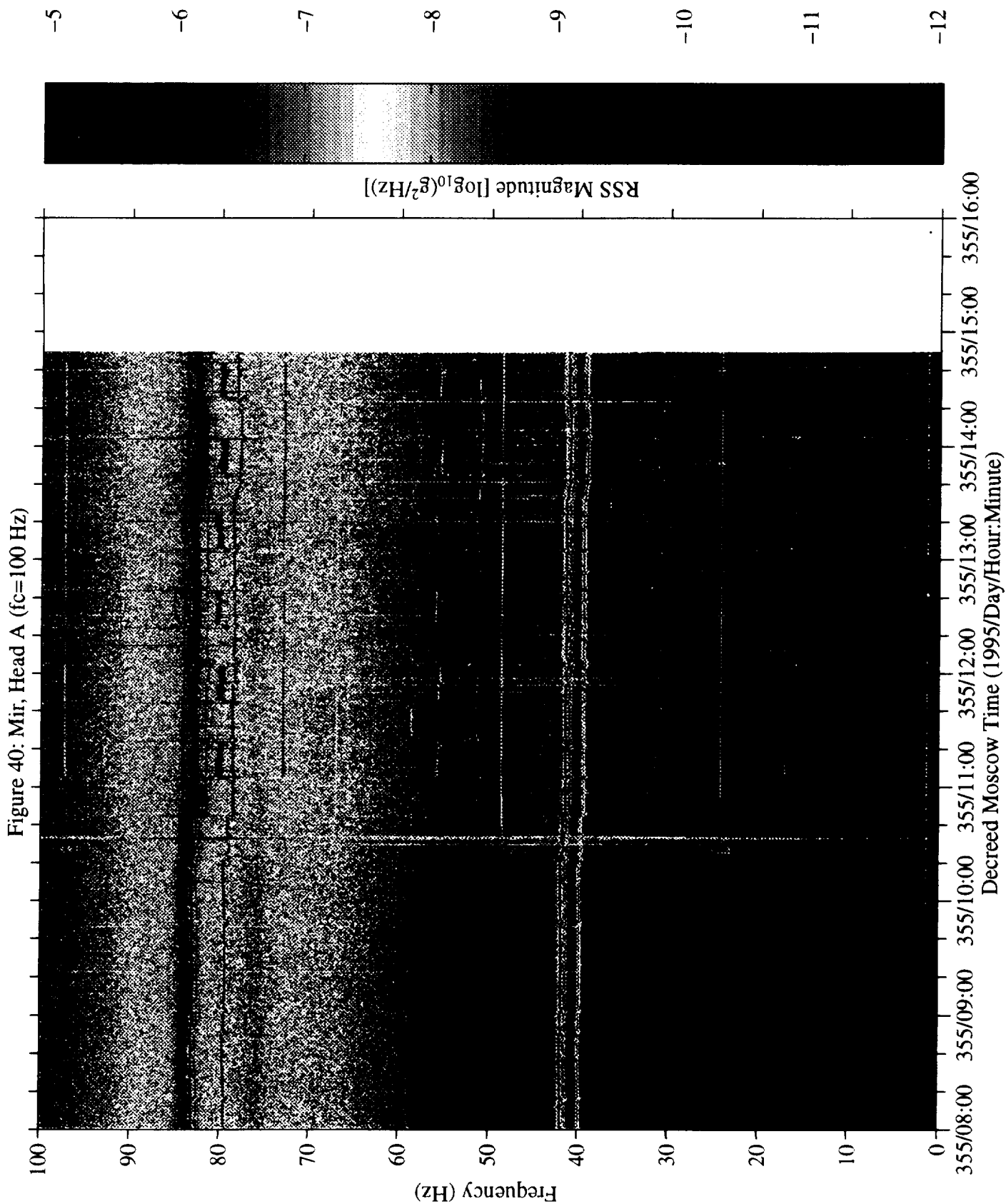












No data are available  
from 1995/355/16:00:00 to 1996/054/08:00:00

No data are available  
from 1995/355/16:00:00 to 1996/054/08:00:00

Figure 41a: Mir, Head A (fc=100 Hz): 10 Second Interval Average

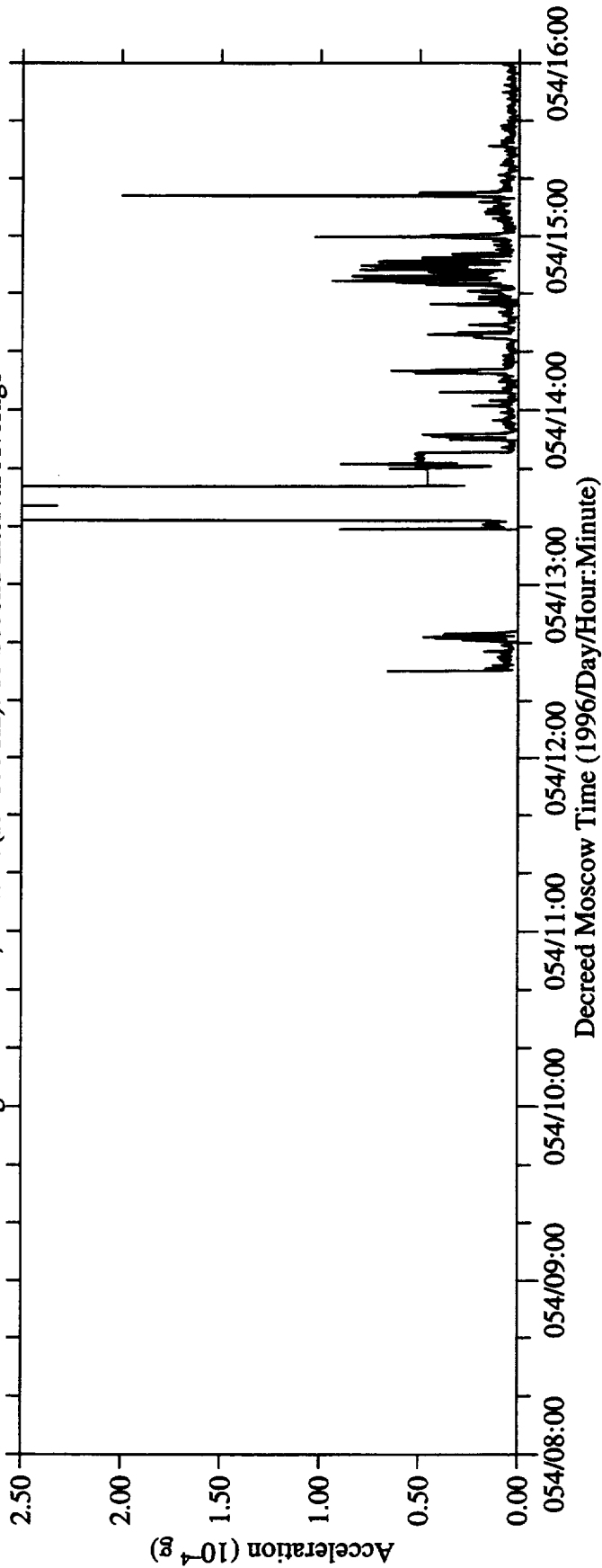
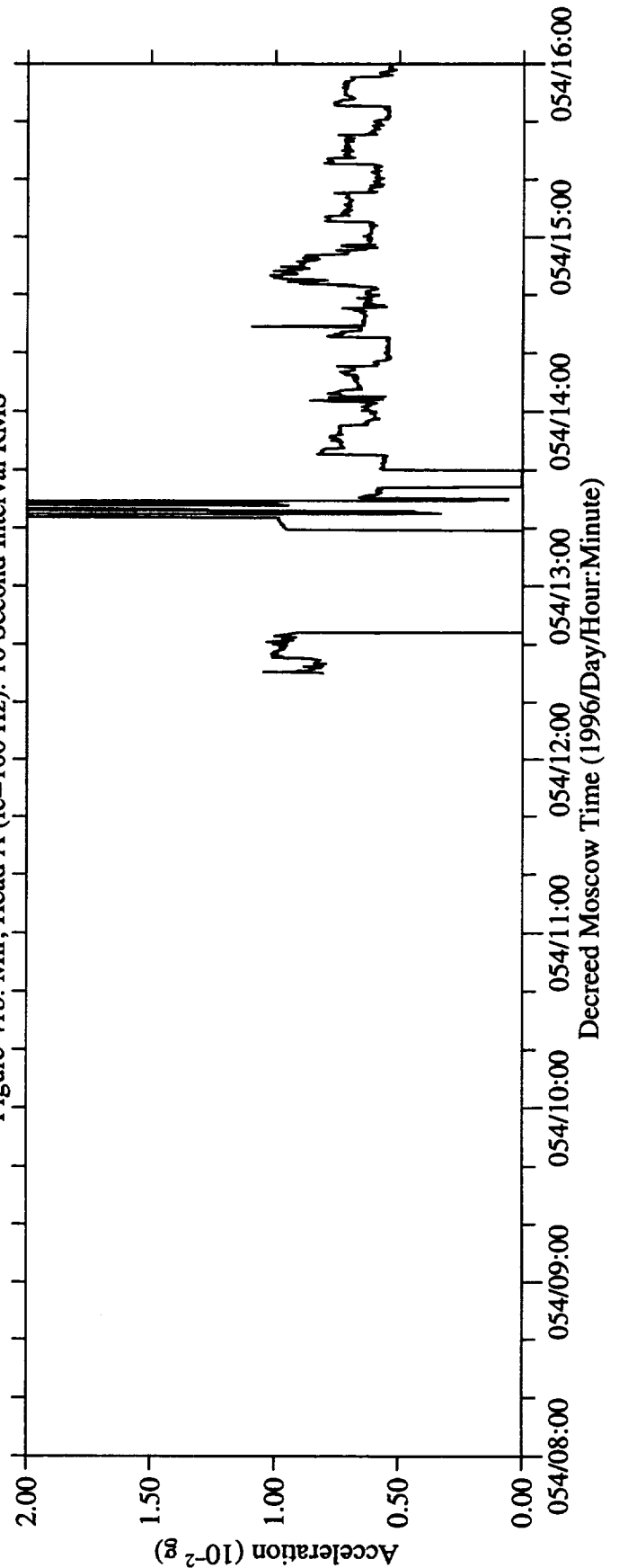
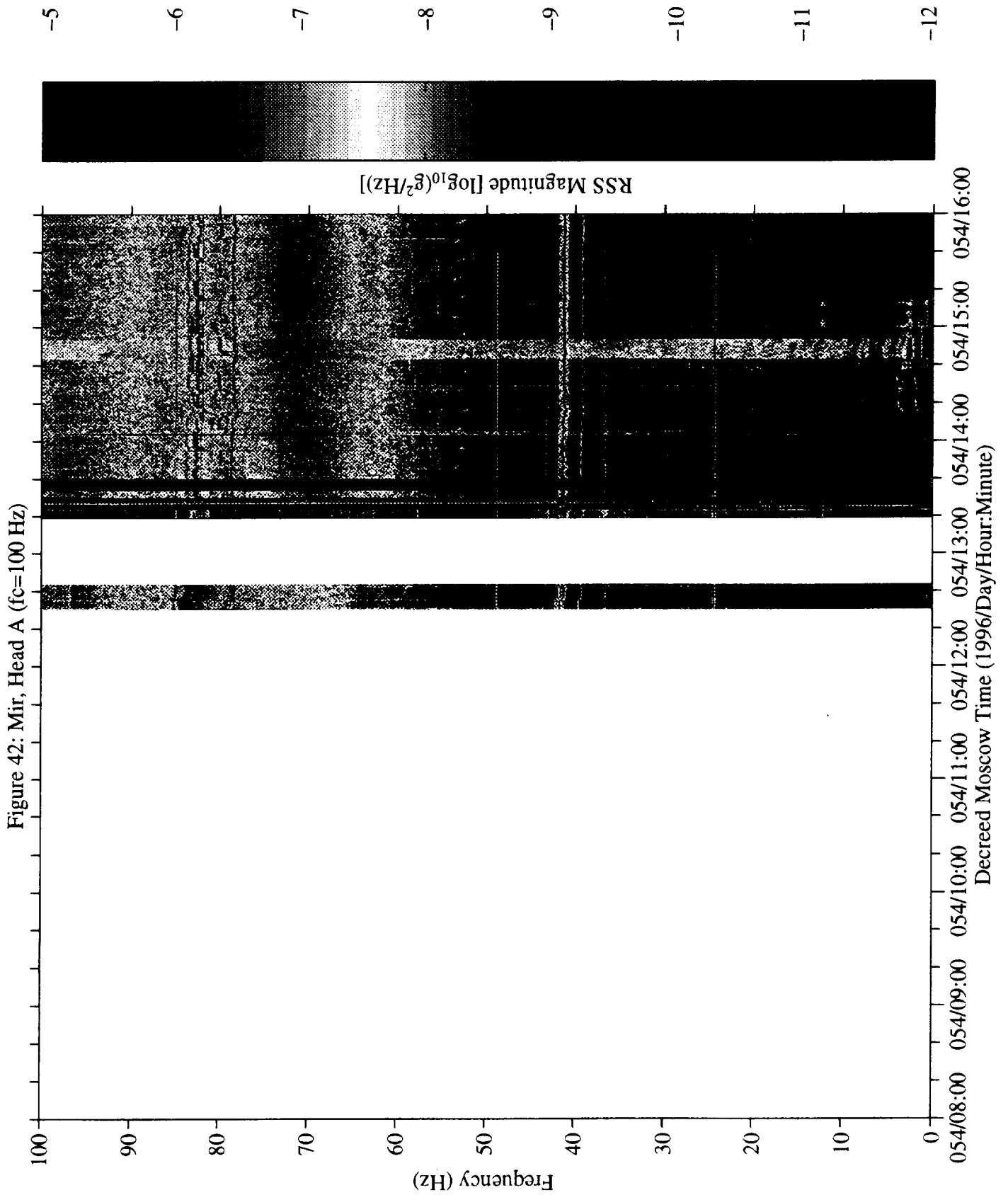
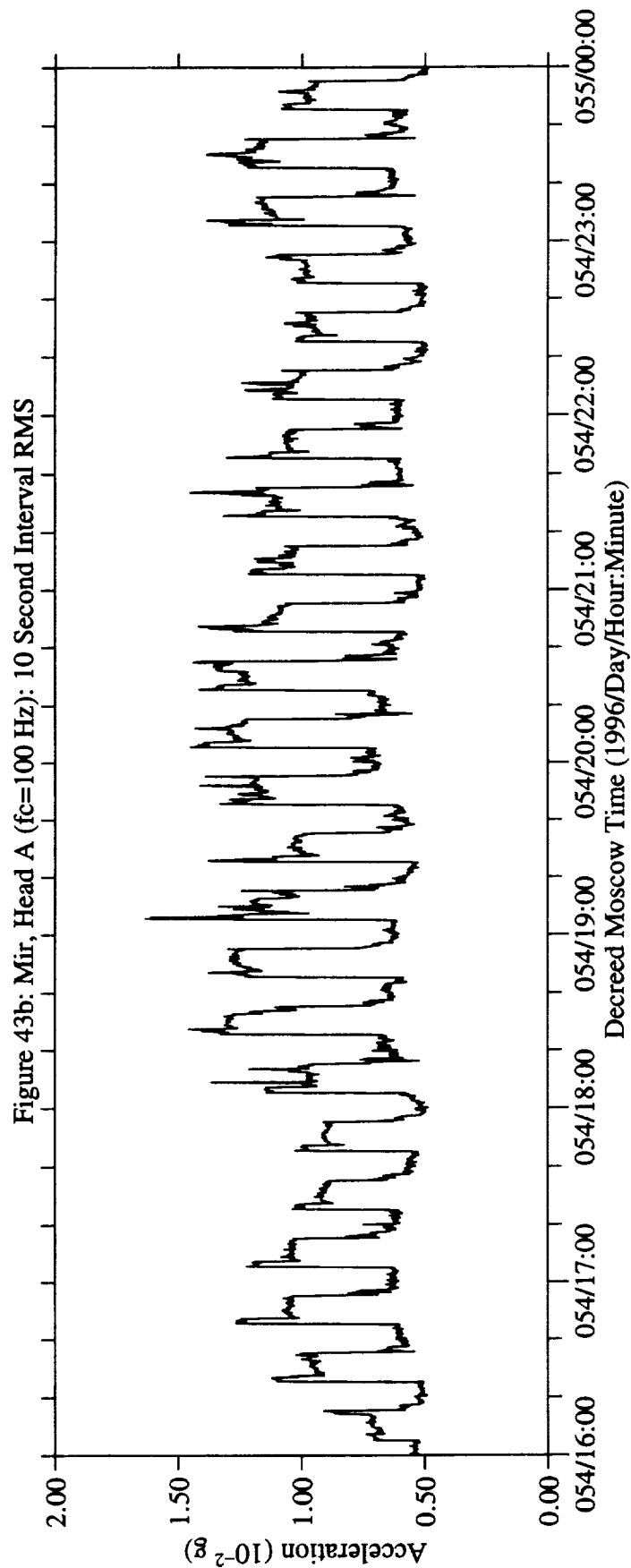
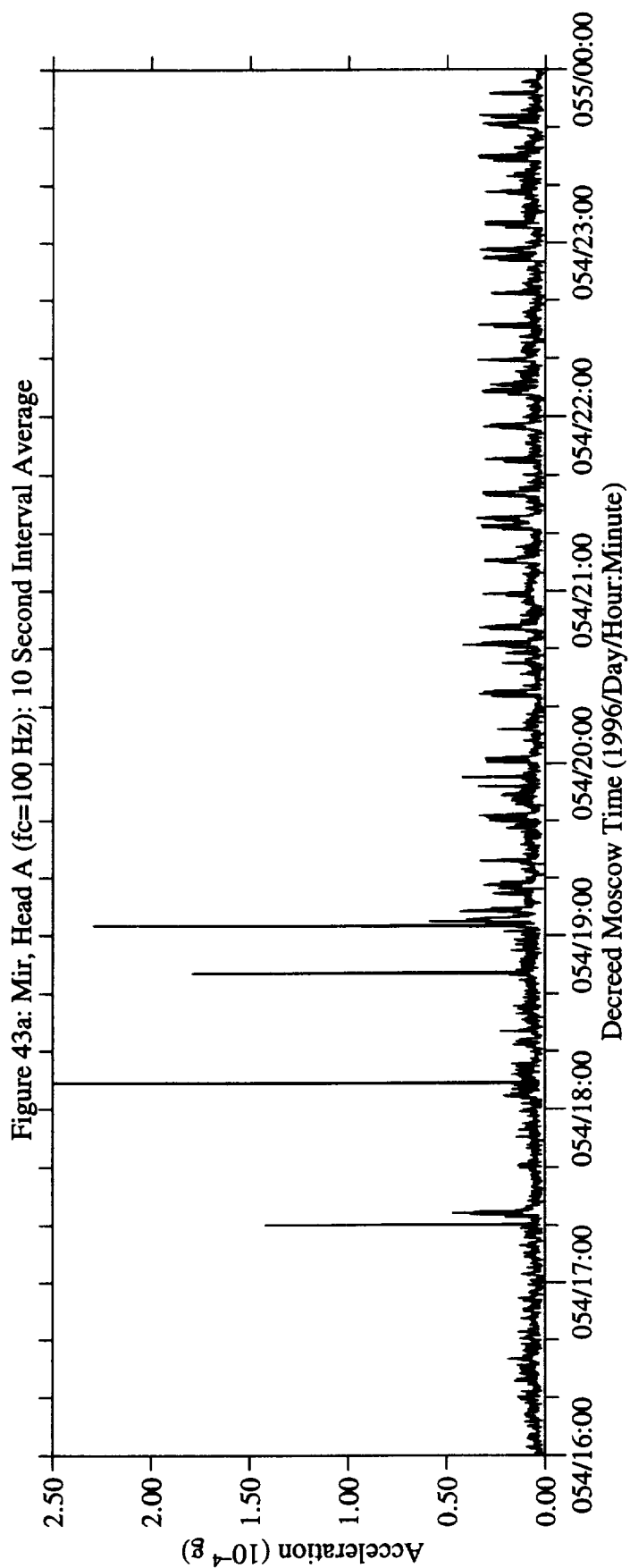


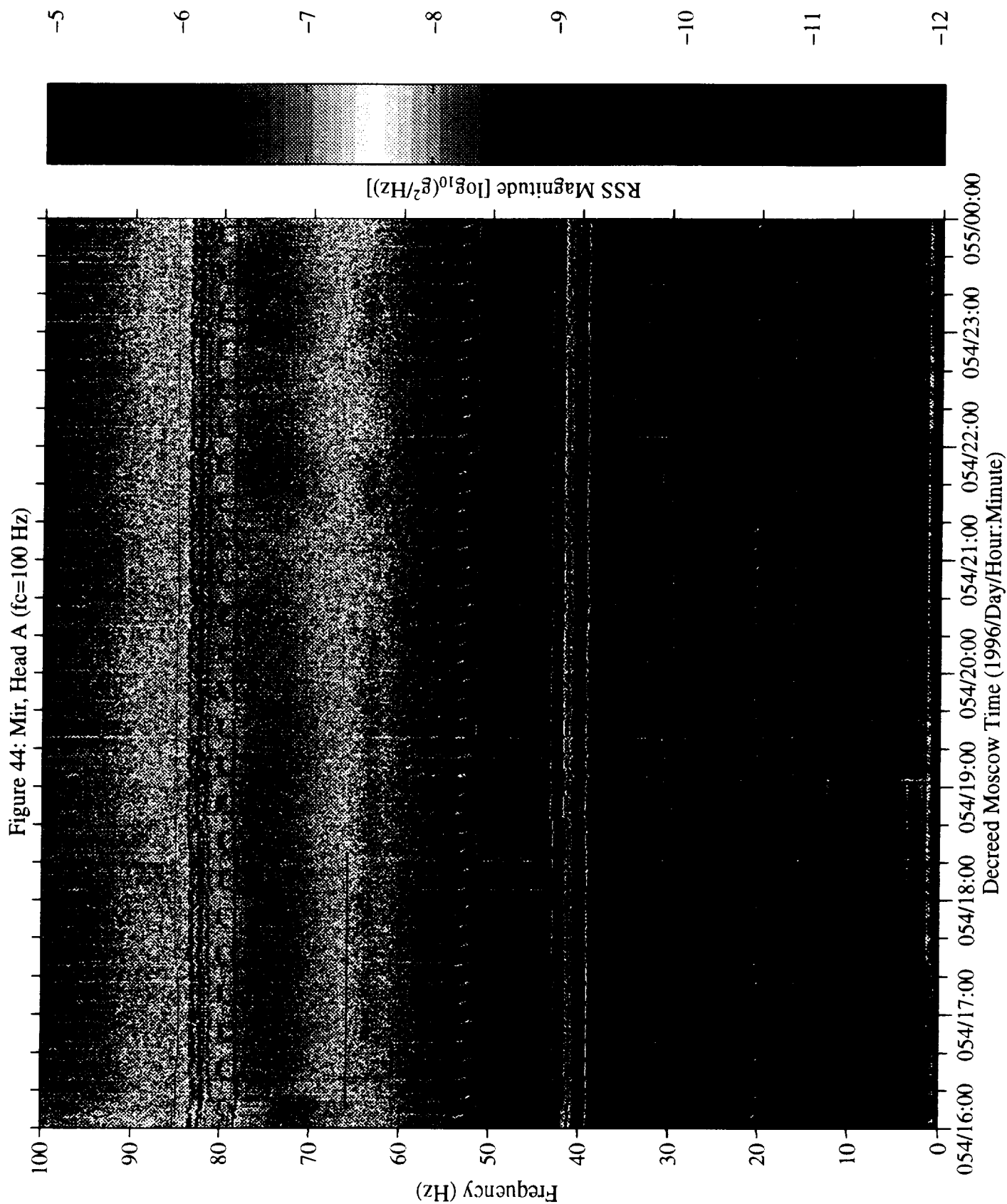
Figure 41b: Mir, Head A (fc=100 Hz): 10 Second Interval RMS

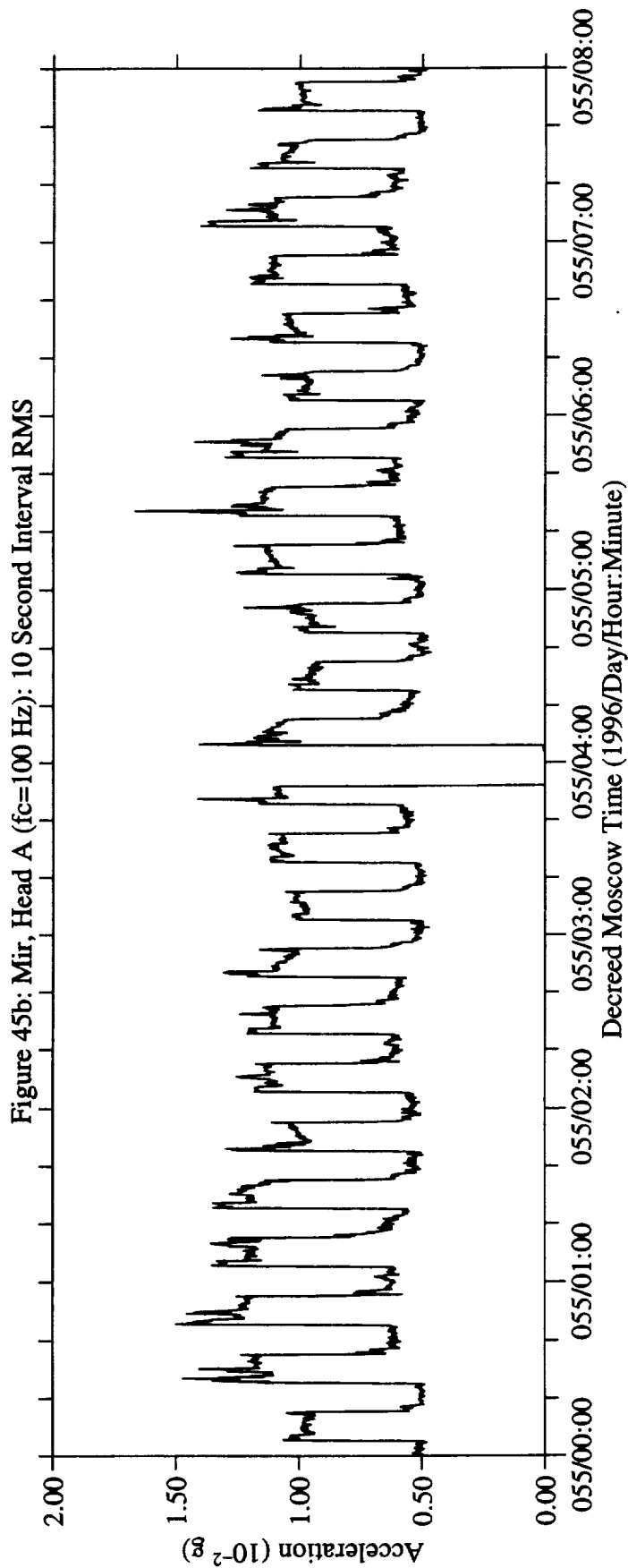
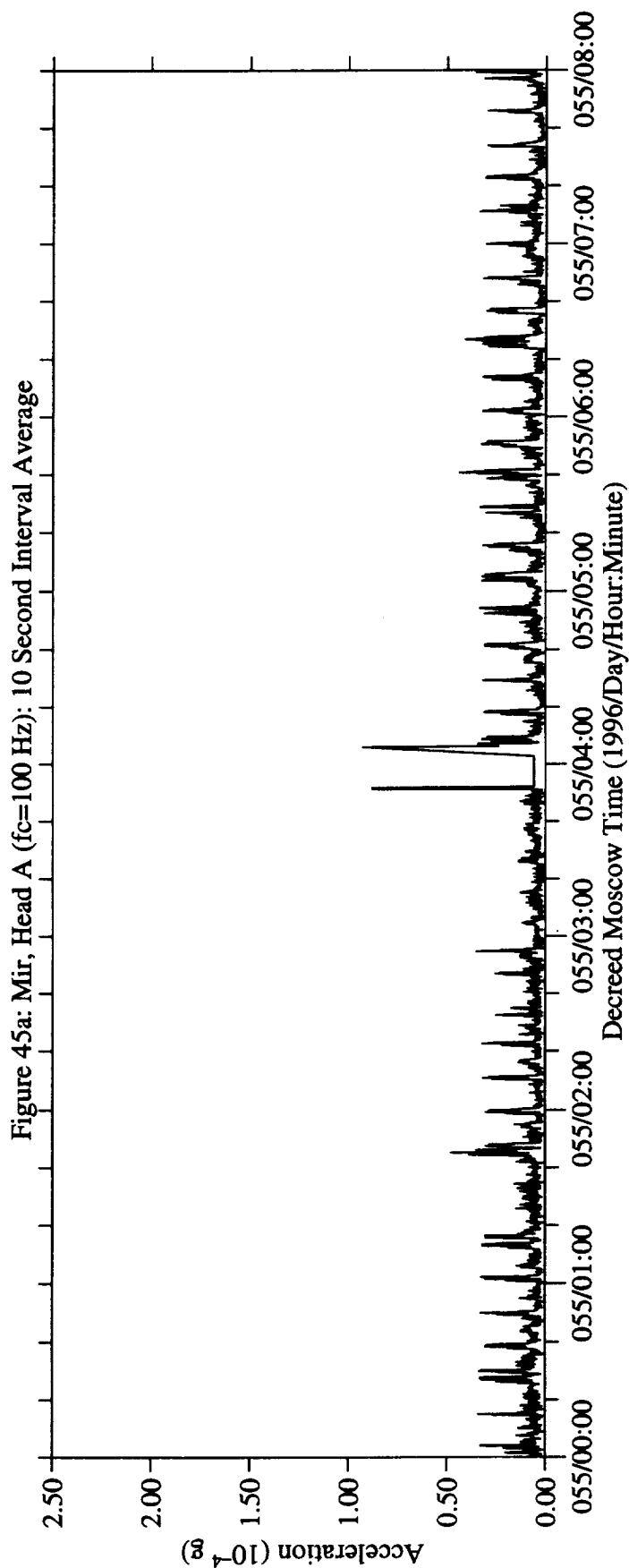


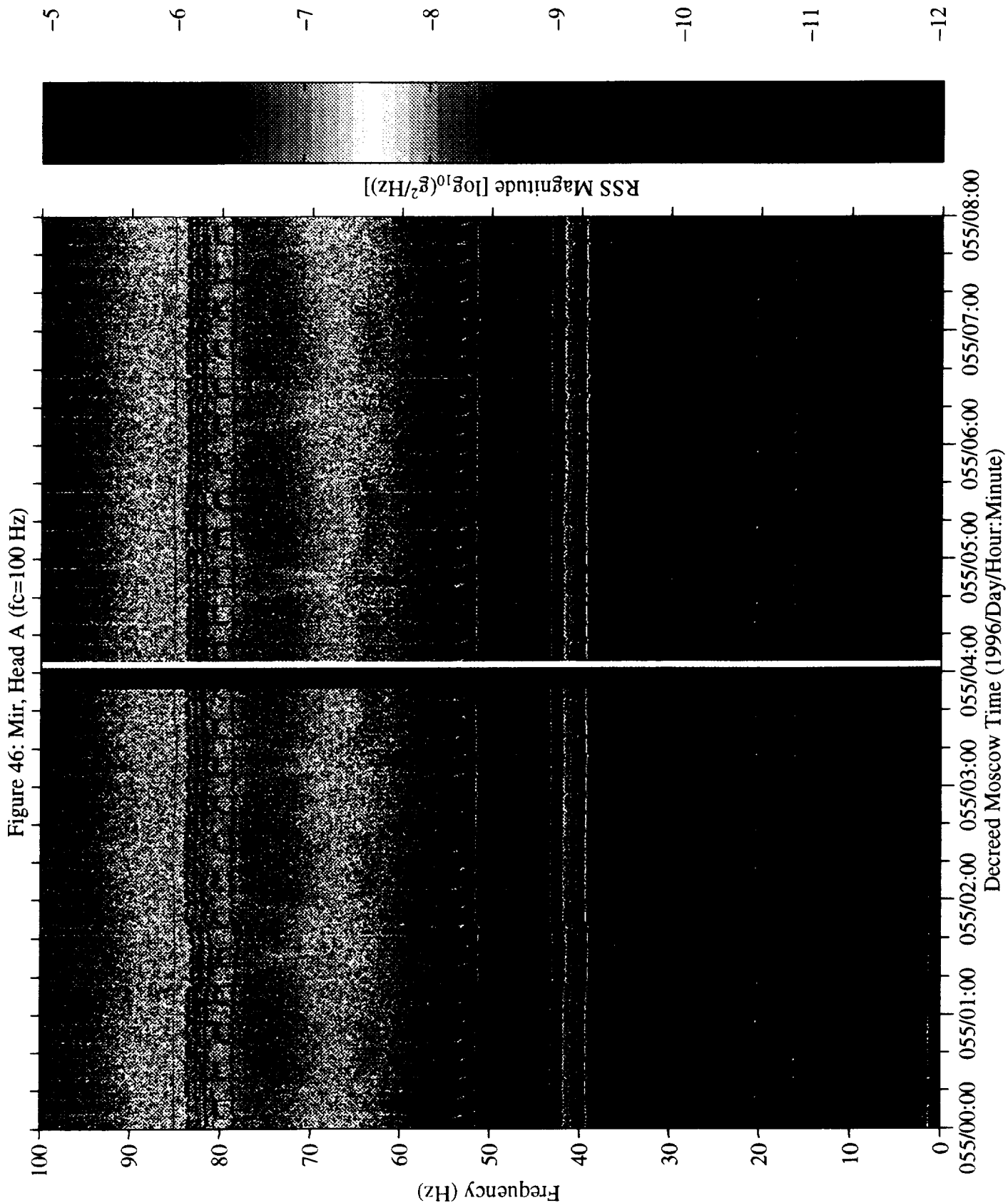


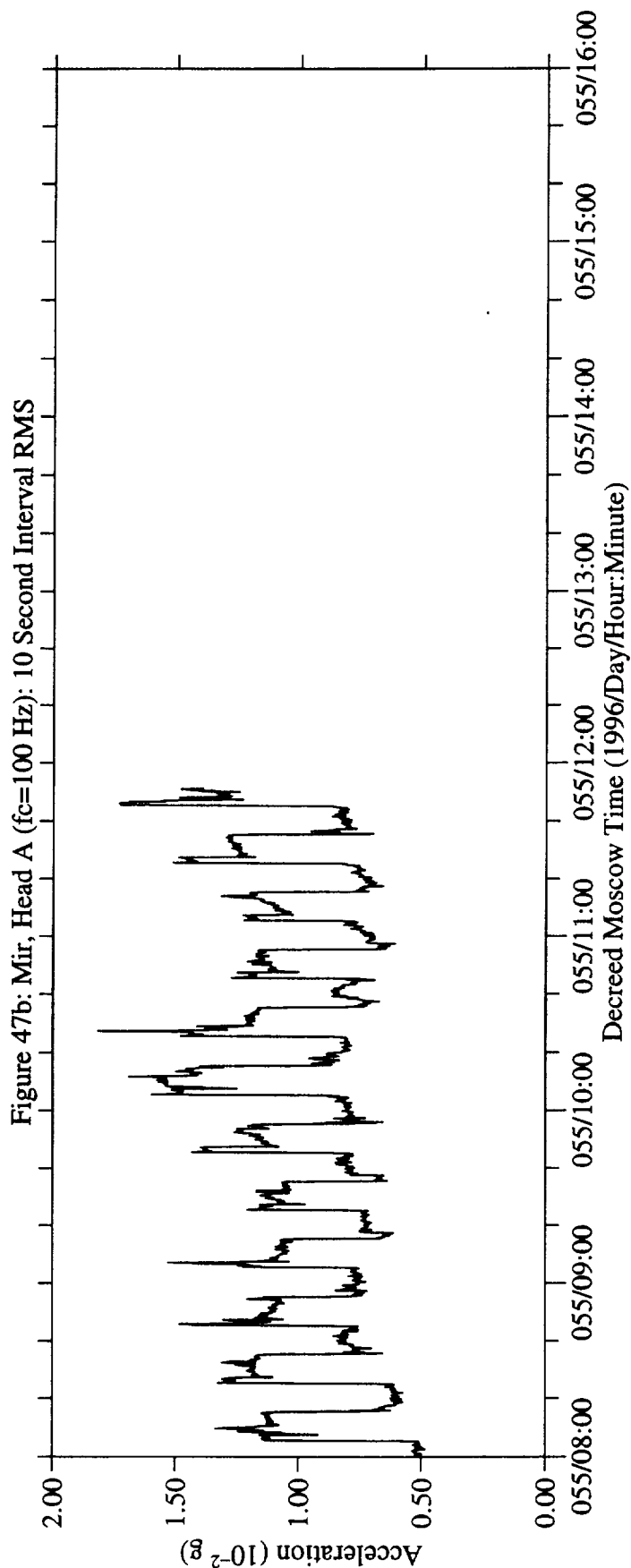
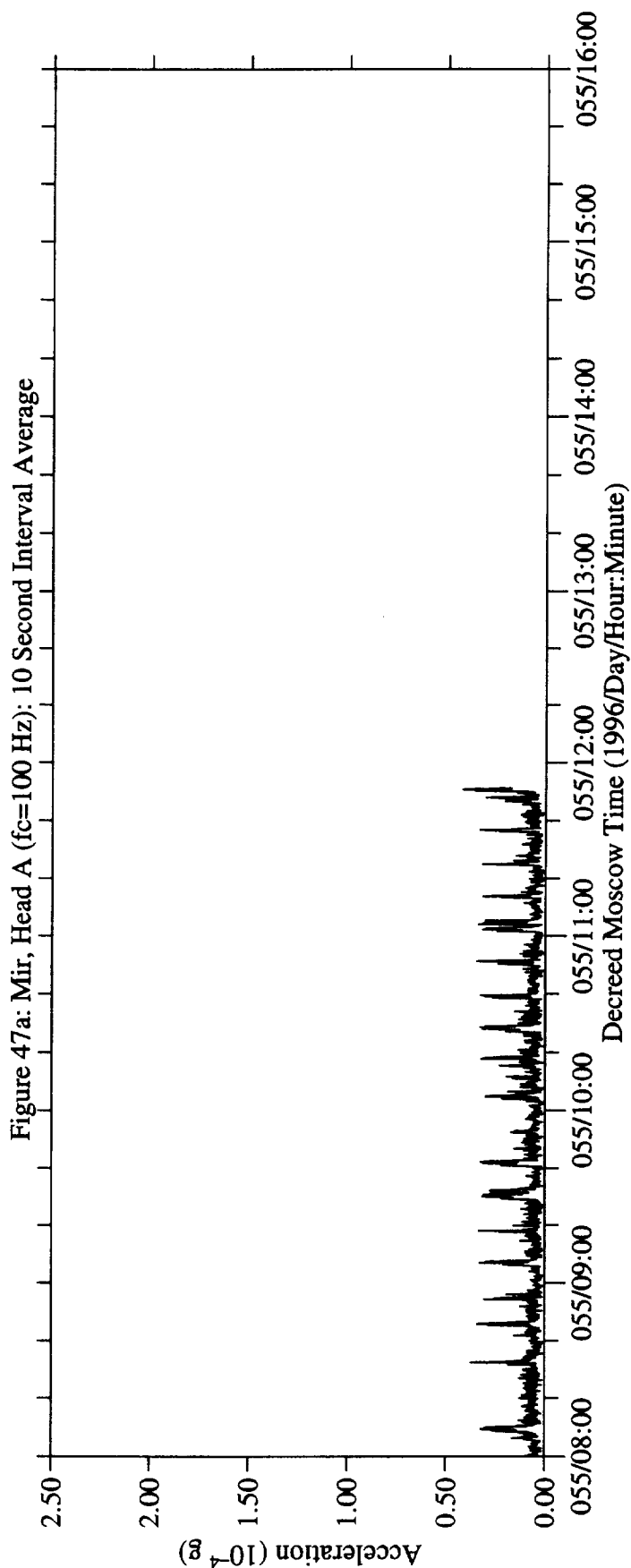


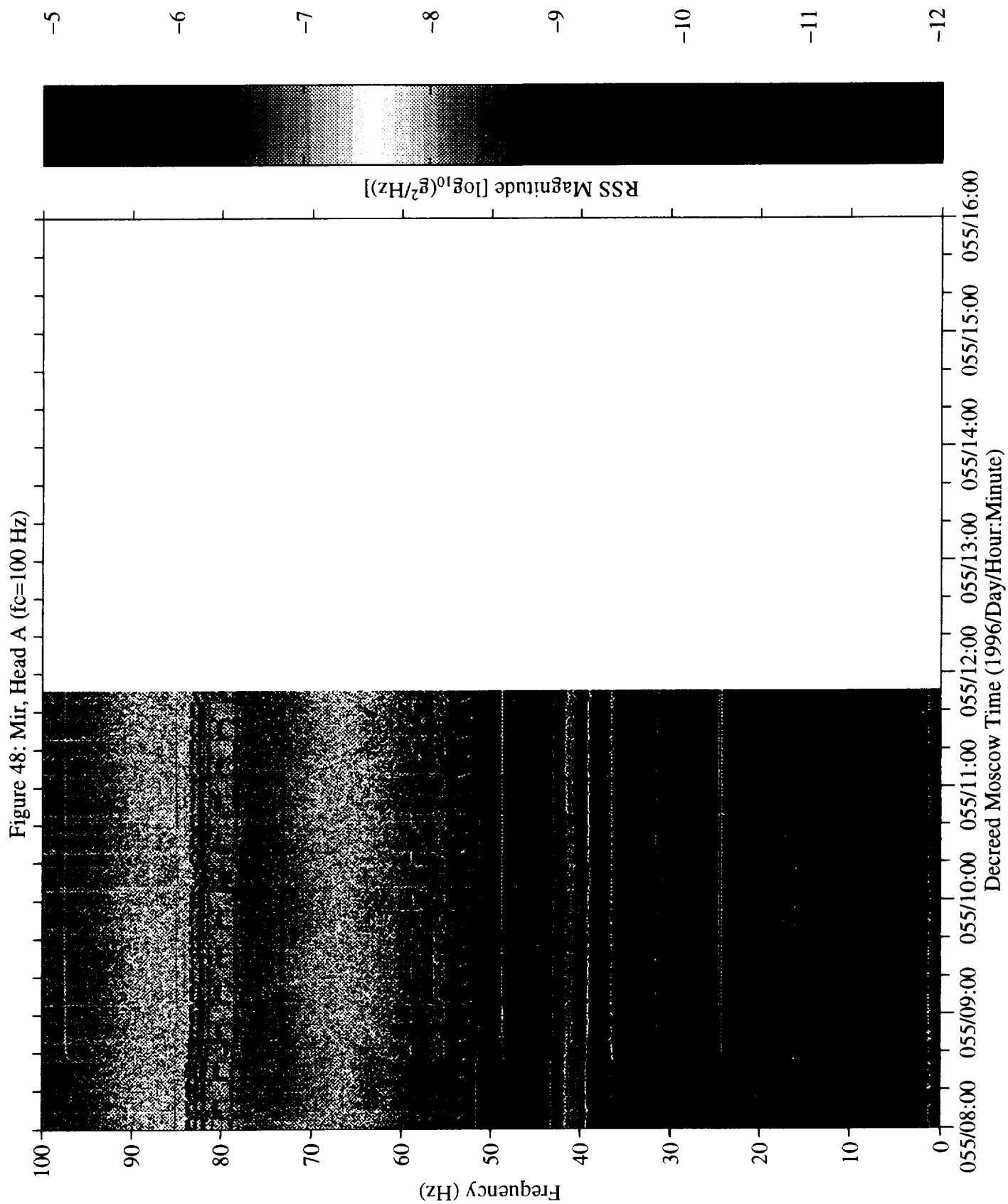
















## Appendix C: SAMS Time Histories and Color Spectrograms for TSH B

The Principal Investigator Microgravity Services (PIMS) group has further processed SAMS data to produce the plots shown here. Three representations of the data are presented here: ten second interval average, ten second interval RMS, and PSD magnitude versus frequency versus time (spectrogram) plots. These calculations are presented in 8 hour plots, with the corresponding average and RMS plots on one page, and the spectrogram on the facing page.

The ten-second interval average plots give an indication of net accelerations which last for a period of 10 seconds or more. Shorter duration, high amplitude accelerations may be seen with this type of plot, however their exact timing and magnitude cannot be extracted. The ten-second interval RMS plots give a measure of the oscillatory content in the acceleration data. Plots of this type may be used to identify times when oscillatory and/or transient deviations from the background acceleration levels occurred.

Color spectrograms are used to show how the microgravity environment varies in intensity with respect to both the time and frequency domains. These spectrograms are provided as an overview of the frequency characteristics of the SAMS data. Each spectrogram is a composite of 8 hour's worth of data. The time resolution used to compute the spectrograms seen here is 40.960 seconds. This corresponds to a frequency resolution of 0.0244 Hz.

These data were collected at 50 samples per second, and a 10 Hz low pass filter was applied to the data by the SAMS unit prior to digitization. Prior to plot production, the raw SAMS data were compensated for gain changes, and then demeaned. Demeaning was accomplished by analyzing individual sections with a nominal length of 30 minutes. Users who are interested in further details for either of these operations are encouraged to contact the PIMS group.

### Interval Average and Root Mean Square Calculations

The interval average plots were produced by calculating the average of ten second intervals of data for each axis. This operation is described as:

$$x_{avg_k} = \frac{1}{M} \sum_{i=1}^M x_{(k-1)M+i},$$

where  $x$  represents the  $x$ ,  $y$ , or  $z$  axis data,  $M$  is the number of points analyzed in an interval, and  $k$  refers to the  $k$ th interval analyzed.

The resulting data streams ( $x_{avg_k}$ ,  $y_{avg_k}$ ,  $z_{avg_k}$ ) are then combined by a vector-magnitude operation.

This computation is expressed mathematically as:  $accel_{avg_k} = \sqrt{x_{avg_k}^2 + y_{avg_k}^2 + z_{avg_k}^2}$ .

The interval RMS plots were produced by taking the root-mean-square of ten second intervals of data for each axis and forming a vector magnitude of the resulting data stream.

The interval RMS operation is expressed mathematically as:  $x_{RMS_k} = \sqrt{\frac{1}{M} \sum_{i=1}^M (x_{(k-1)M+i})^2}$ .

The same definitions apply for  $y$ ,  $M$ , and  $k$  as in the interval average computation. The resulting data streams are combined by a vector-magnitude operation.

### Power Spectral Density versus Frequency versus Time Calculations

In order to produce the spectrogram image, Power Spectral Densities were computed for successive time intervals (the length of the interval is equal to the time resolution). For the PSD computation, a Hanning window was applied. In order to combine all three axes into a single plot to show an overall level, a Vector-Magnitude (VM) operation was performed. Stated mathematically:

$$VM_k = \sqrt{PSD_{x_k}^2 + PSD_{y_k}^2 + PSD_{z_k}^2}.$$

By imaging the base 10 logarithm ( $\log_{10}$ ) magnitude as a color and stacking successive PSDs from left to right, variations of acceleration magnitude and frequency are shown as a function of time. Colors are assigned to discrete magnitude ranges, so that there are 64 colors assigned to the entire range of magnitudes shown.

The colorbar limits are chosen in order to maximize the data value and visibility in a given set of spectrogram plots. Data which fall outside of these limits will be imaged as either the highest or lowest magnitude, depending on which side they have saturated. For this report, less than 1% of the total points lie below the lower limit, and less than 1% of the total points lie above the upper limit. If an area of interest seems to be saturated, care should be taken in that the actual values may lie above or below the color mapping shown on the plot.

Due to the nature of spectrograms, care should be taken to not merely read a color's numeric value as being the "amount" of acceleration that is present at a given frequency. In order to get this type of information, the PSDs must be integrated between two frequencies. These frequencies (lower and upper) form the "band" of interest. The result of this integration is the  $g_{\text{RMS}}$  acceleration level in the  $[f_{\text{lower}}, f_{\text{upper}}]$  band. The PIMS group is able to provide this type of analysis on a per-request basis.

Plot gaps (if any exist) are shown by either white or dark blue areas on the page. Care should be taken to not mistake a plot gap (represented by a blue vertical band) with a quiet period. If a plot gap exists for an entire plot (or series of successive plots), a comment is placed on the page to let the user know there is a gap in the data. These "no data available" comments will not show exact times for which the data are not available, but will only indicate missing plots.

#### Contacting PIMS

To request additional analysis or information, users are encouraged to send an e-mail to [pims@lerc.nasa.gov](mailto:pims@lerc.nasa.gov), or FAX a request to (216) 433-8545.

Figure 1a: Mir, Head B (fc=10 Hz): 10 Second Interval Average

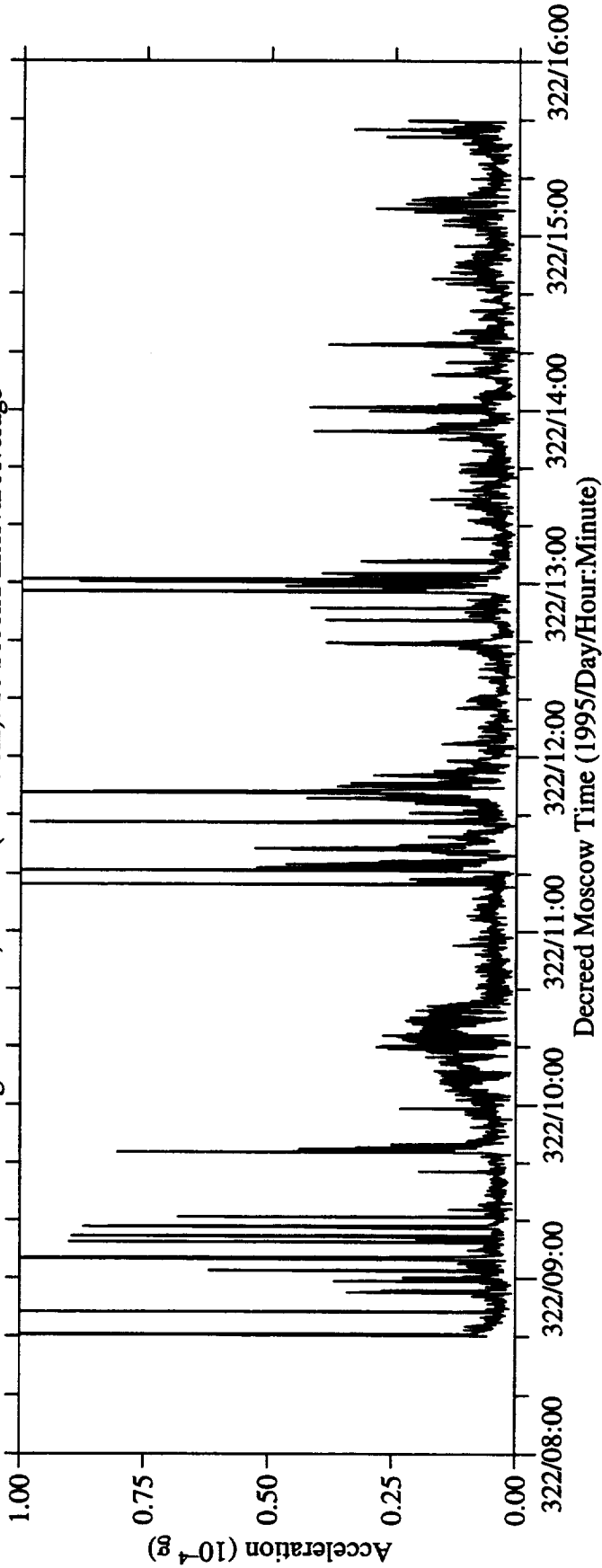
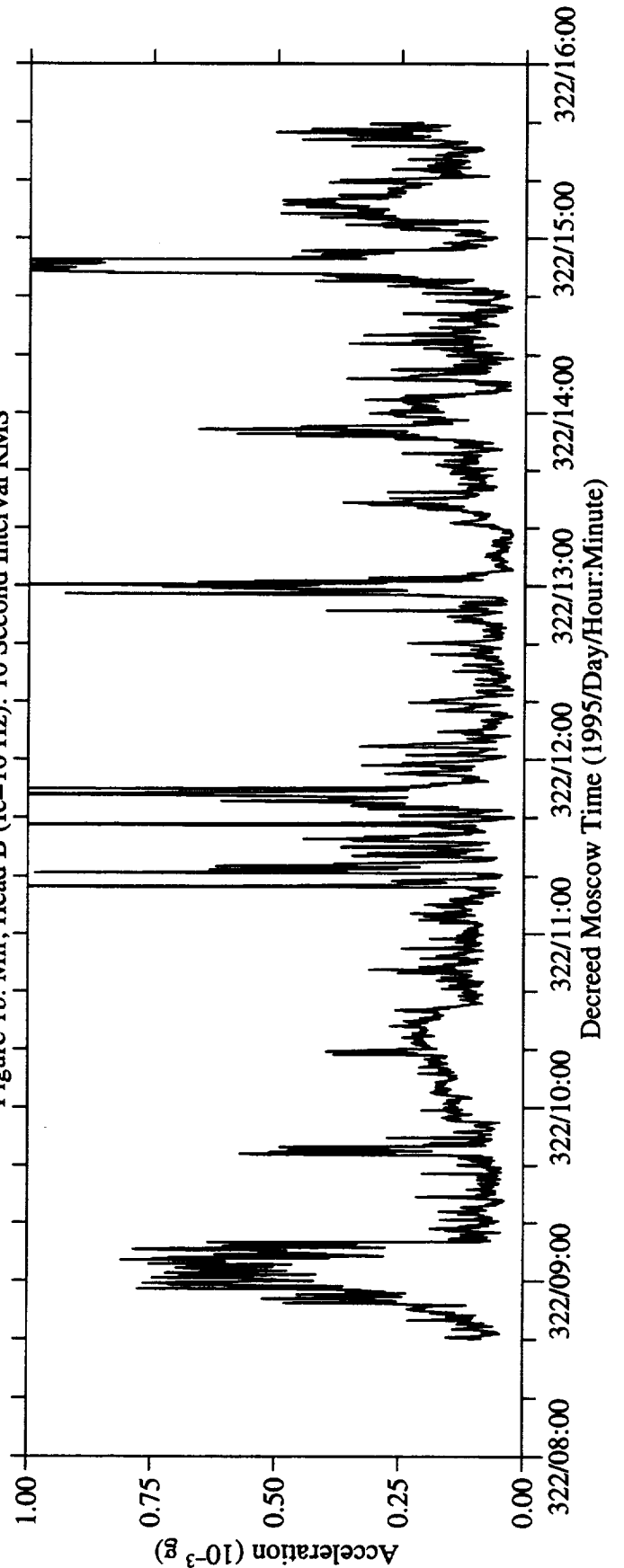
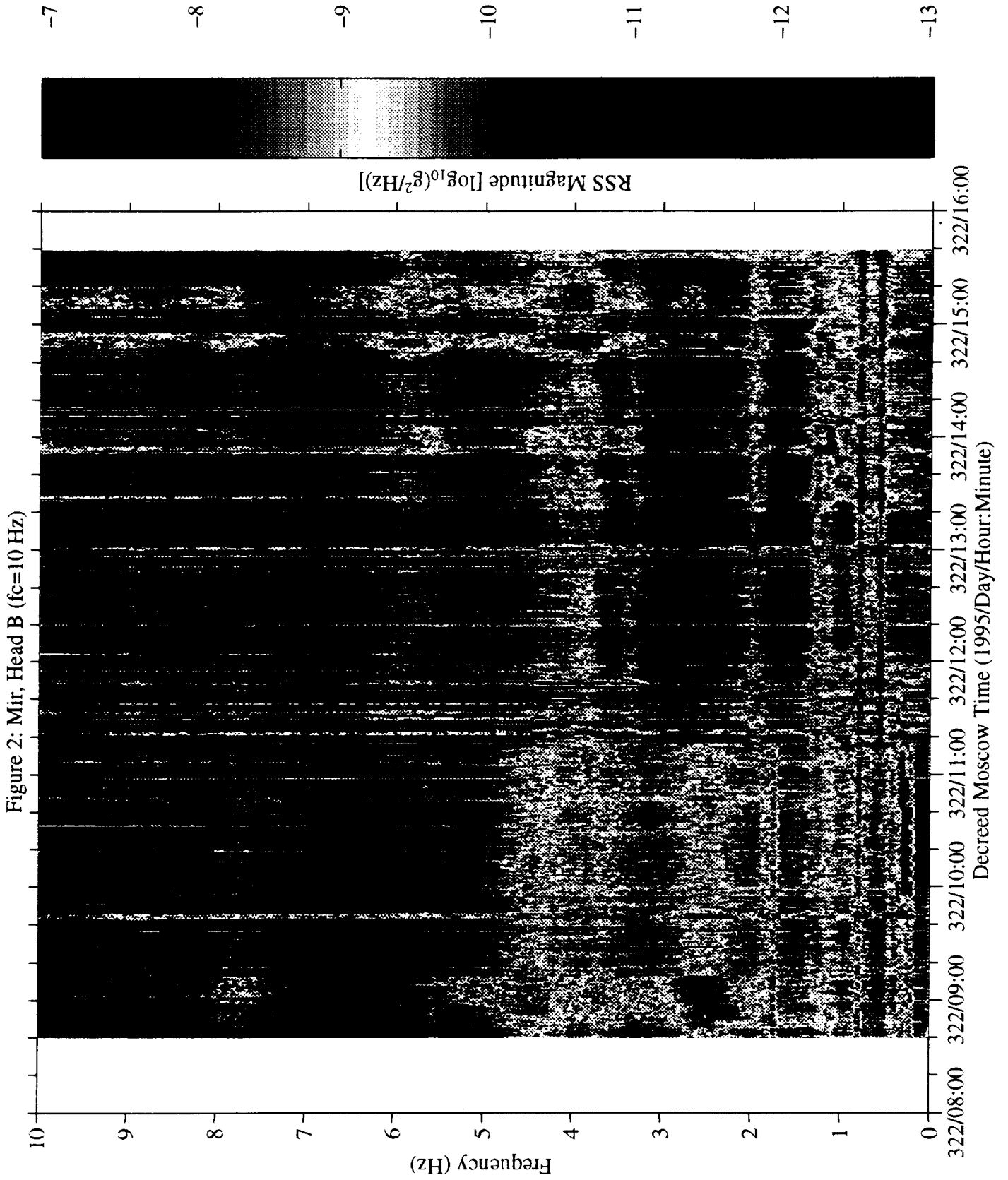


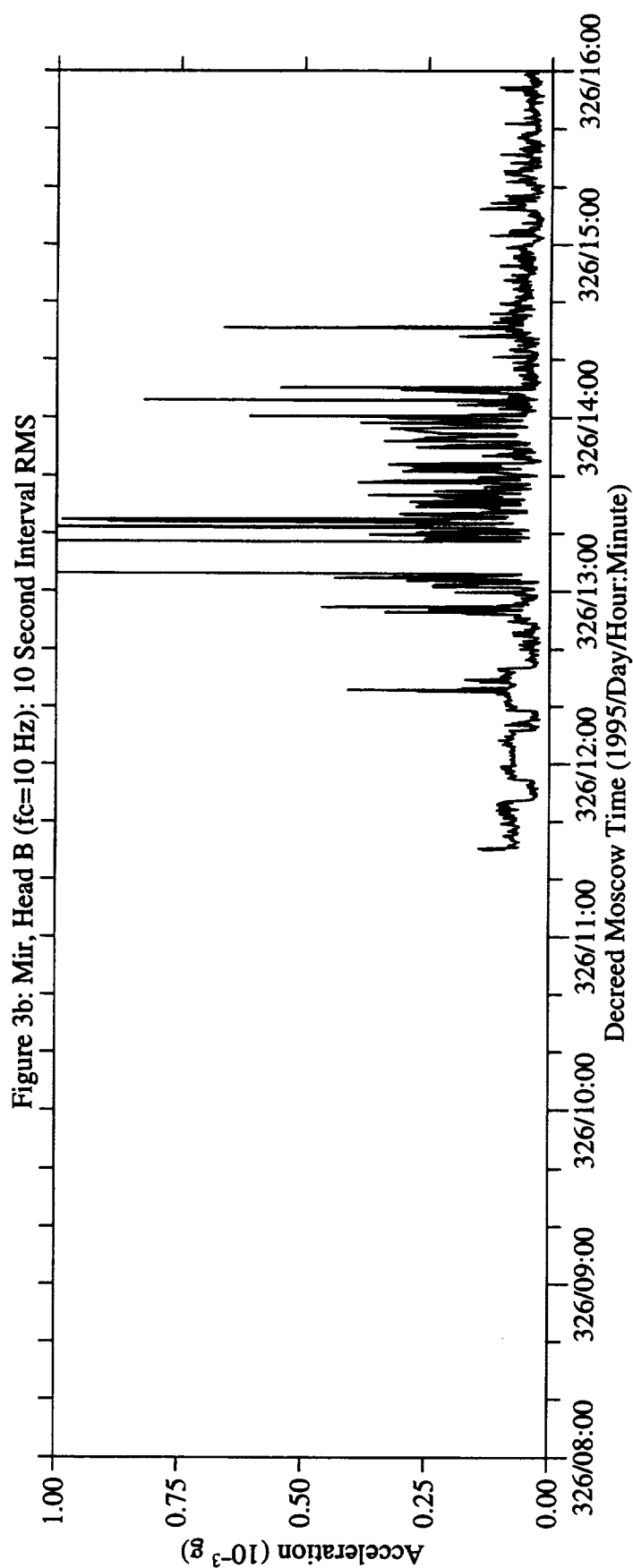
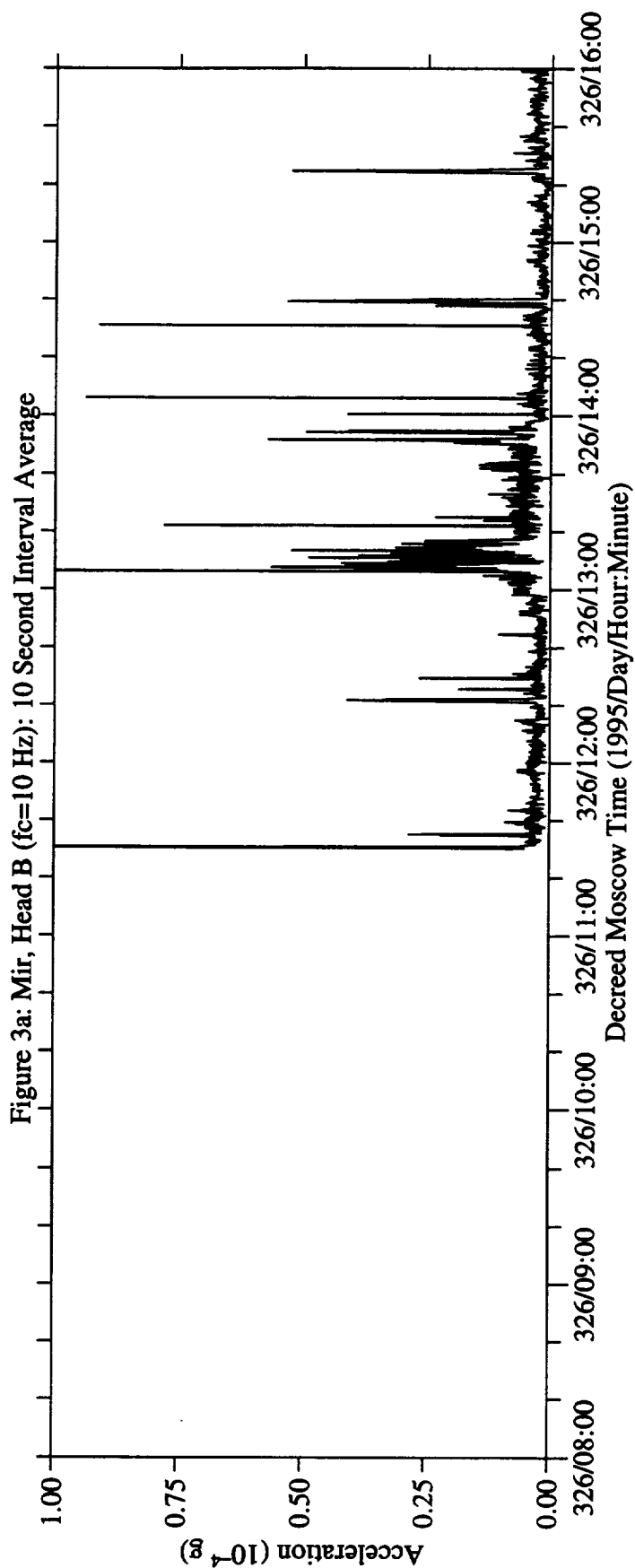
Figure 1b: Mir, Head B (fc=10 Hz): 10 Second Interval RMS



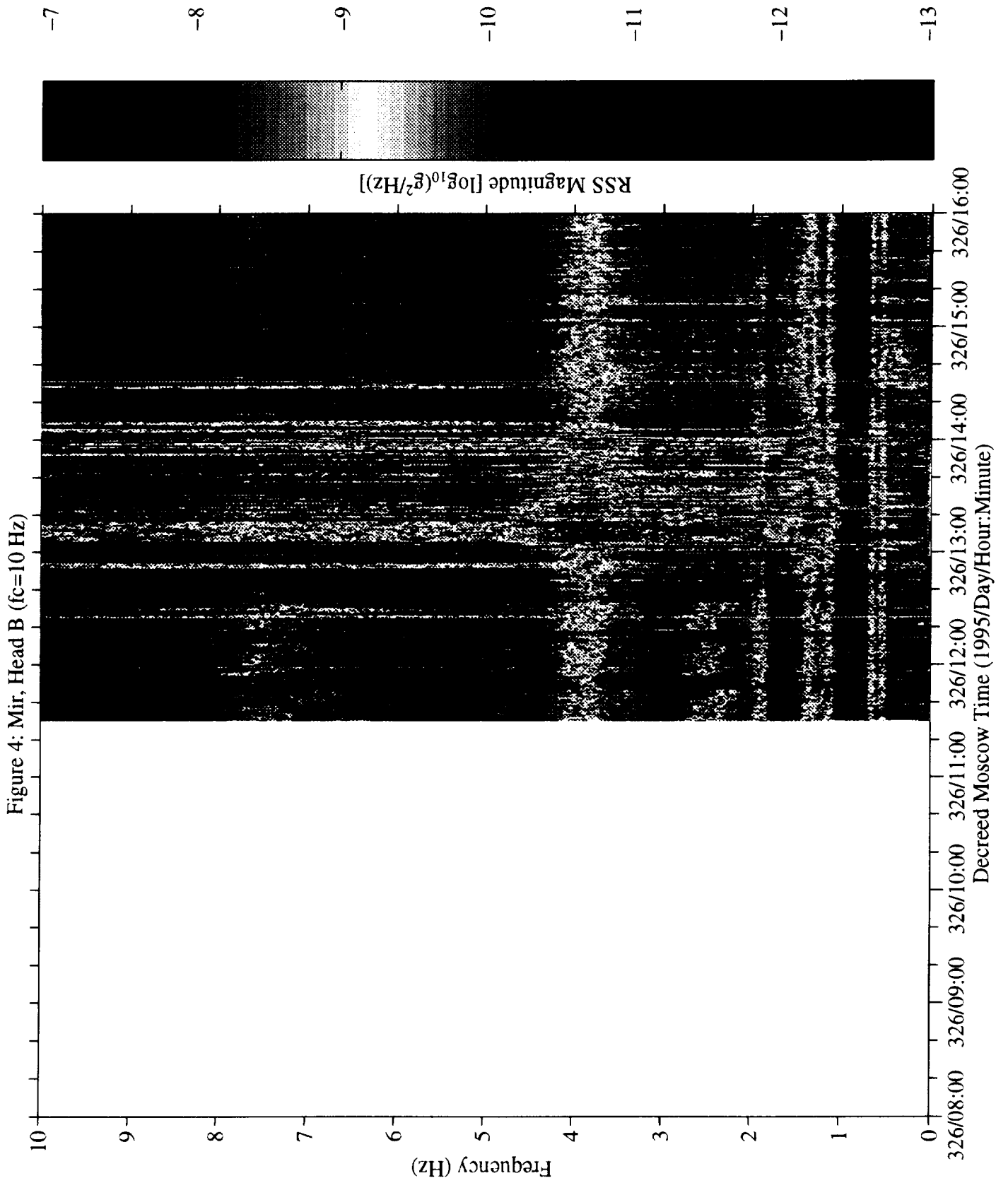


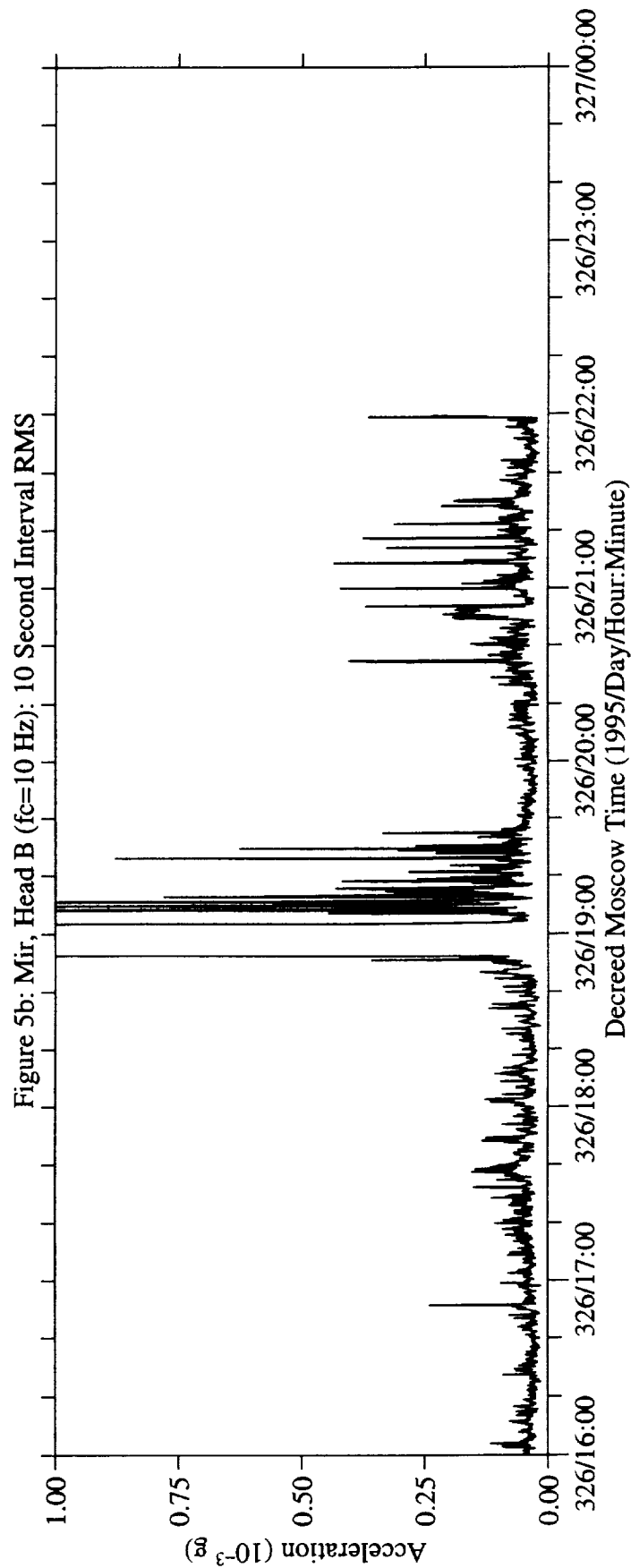
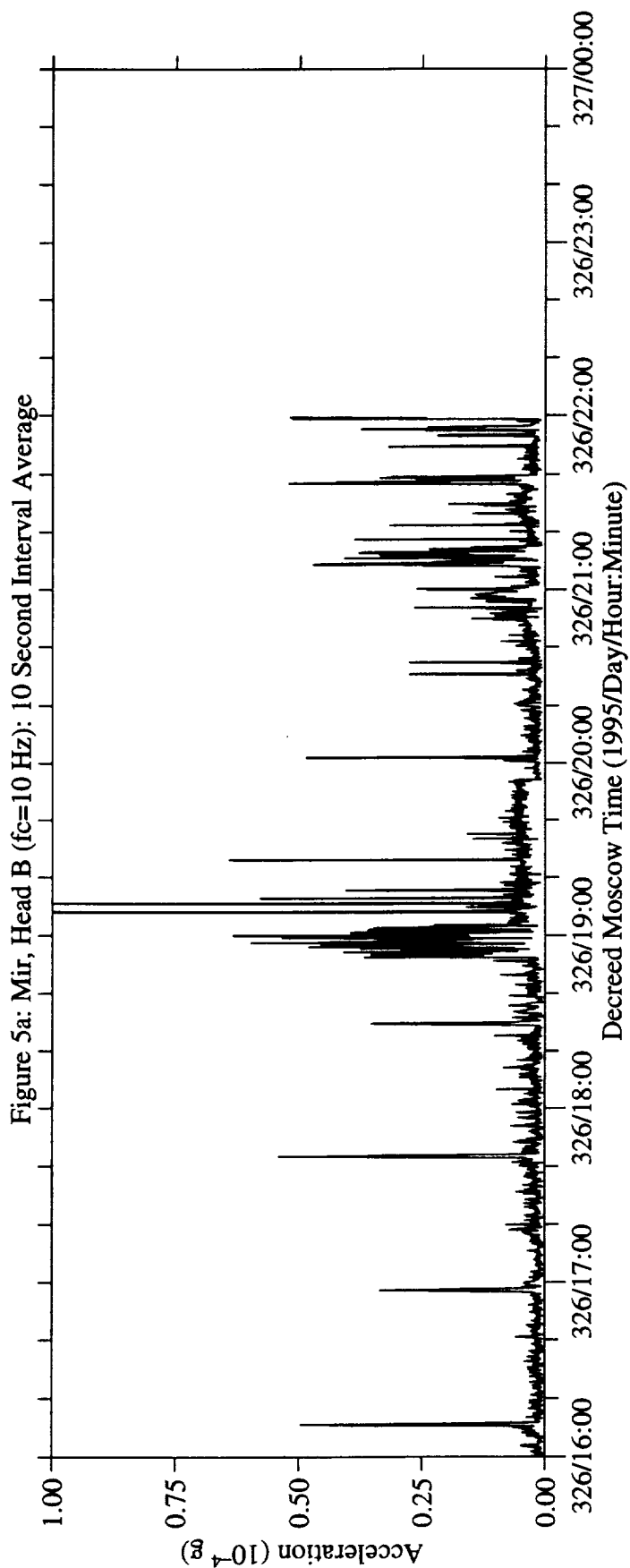
No data are available  
from 322/16:00:00 to 326/08:00:00

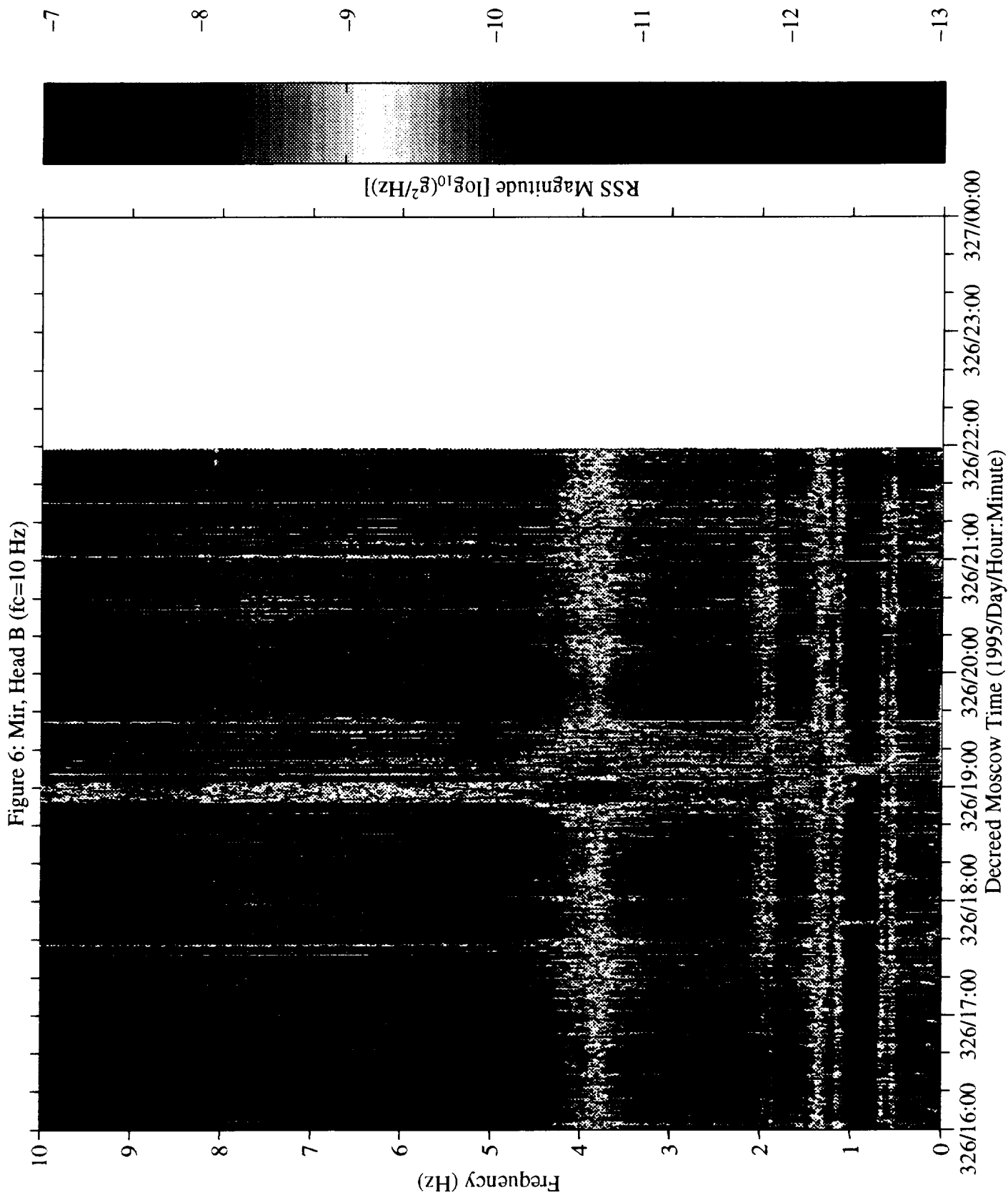
No data are available  
from 322/16:00:00 to 326/08:00:00











No data are available  
from 327/00:00:00 to 334/08:00:00

No data are available  
from 327/00:00:00 to 334/08:00:00

Figure 7a: Mir, Head B (fc=10 Hz): 10 Second Interval Average

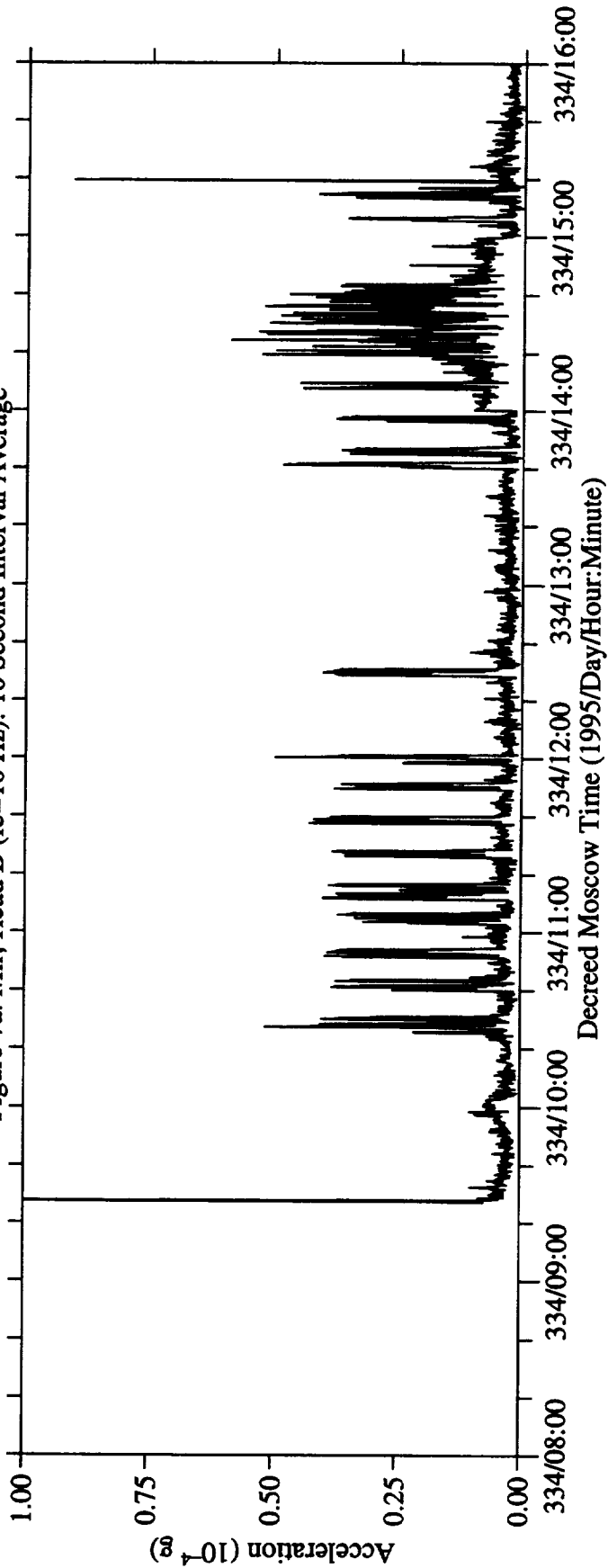
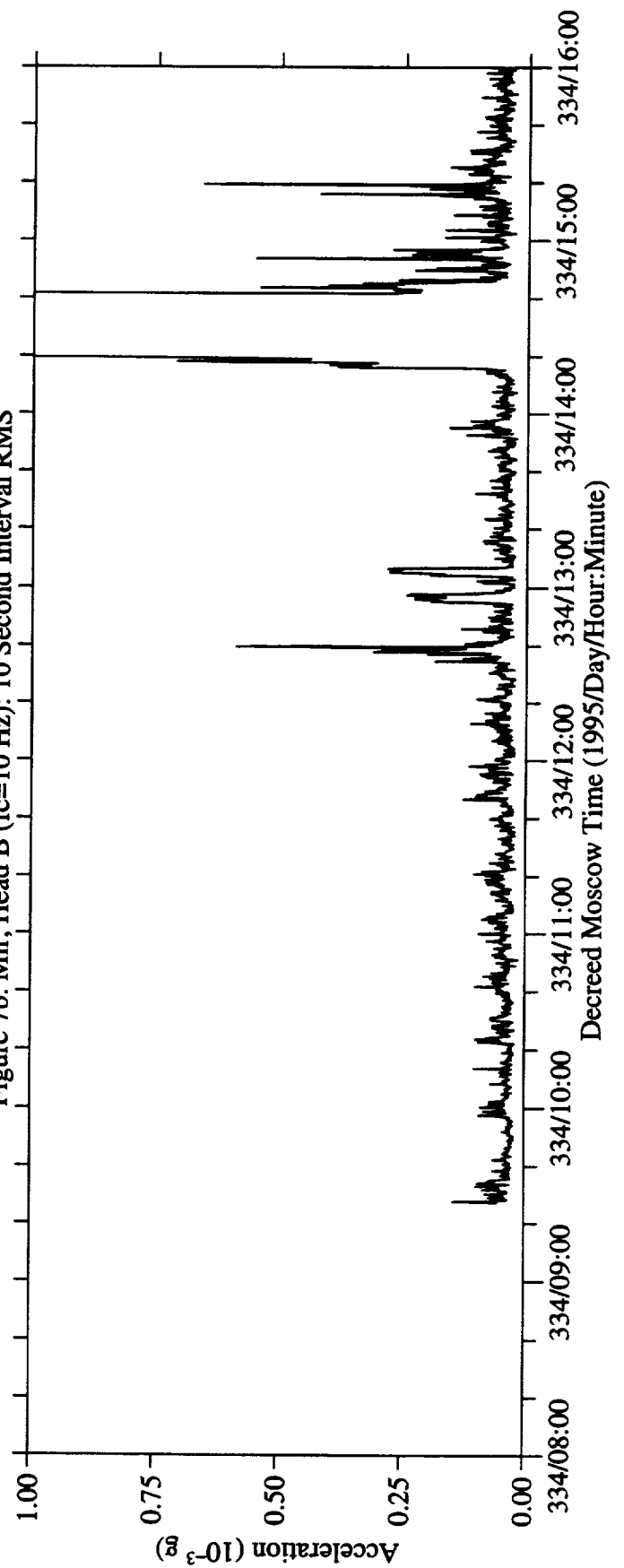
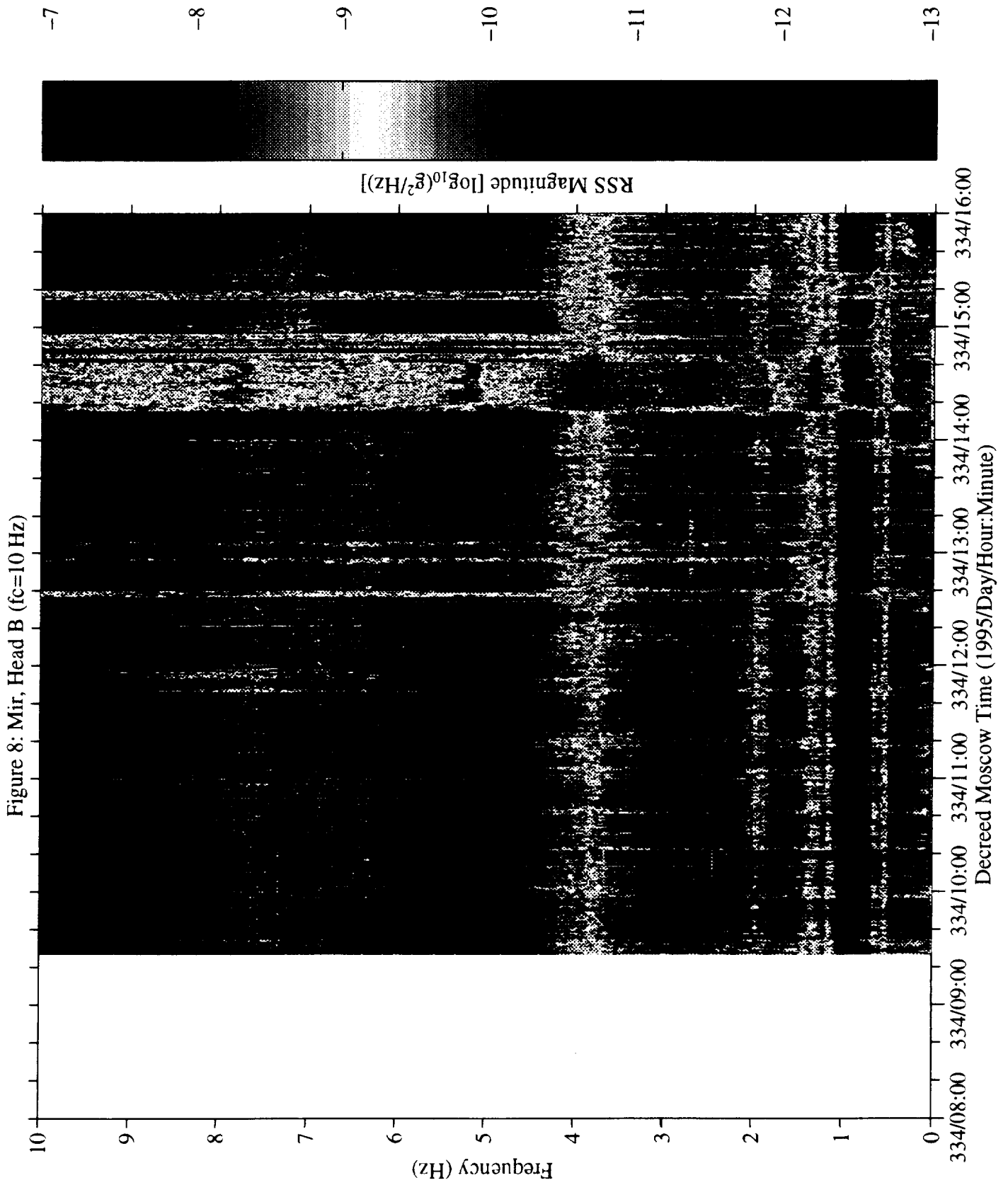
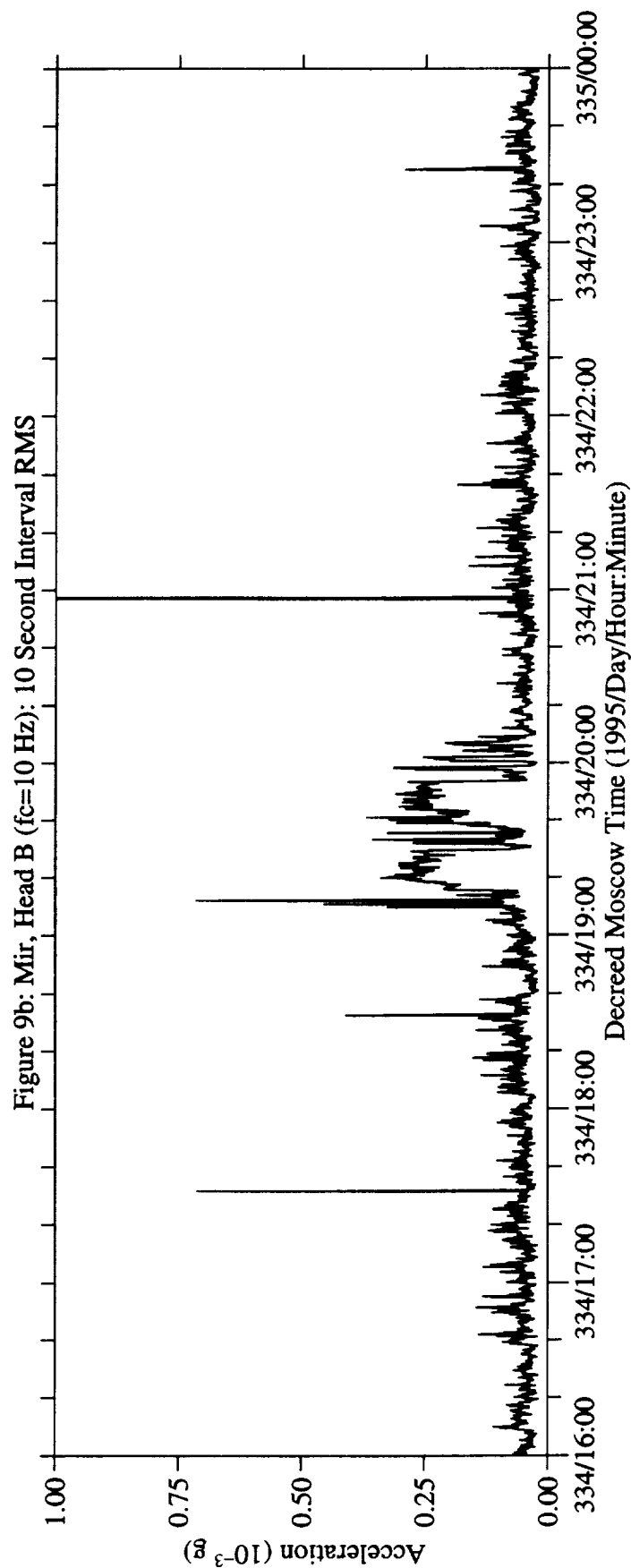
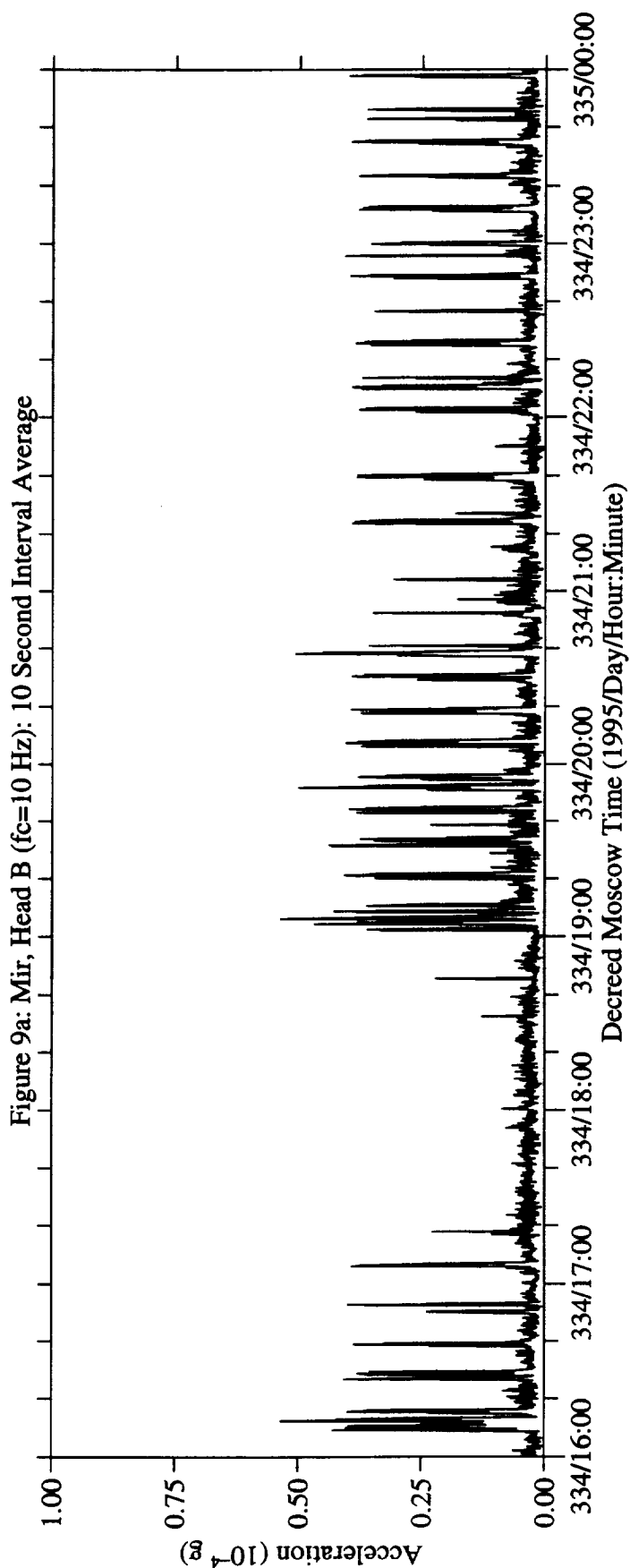


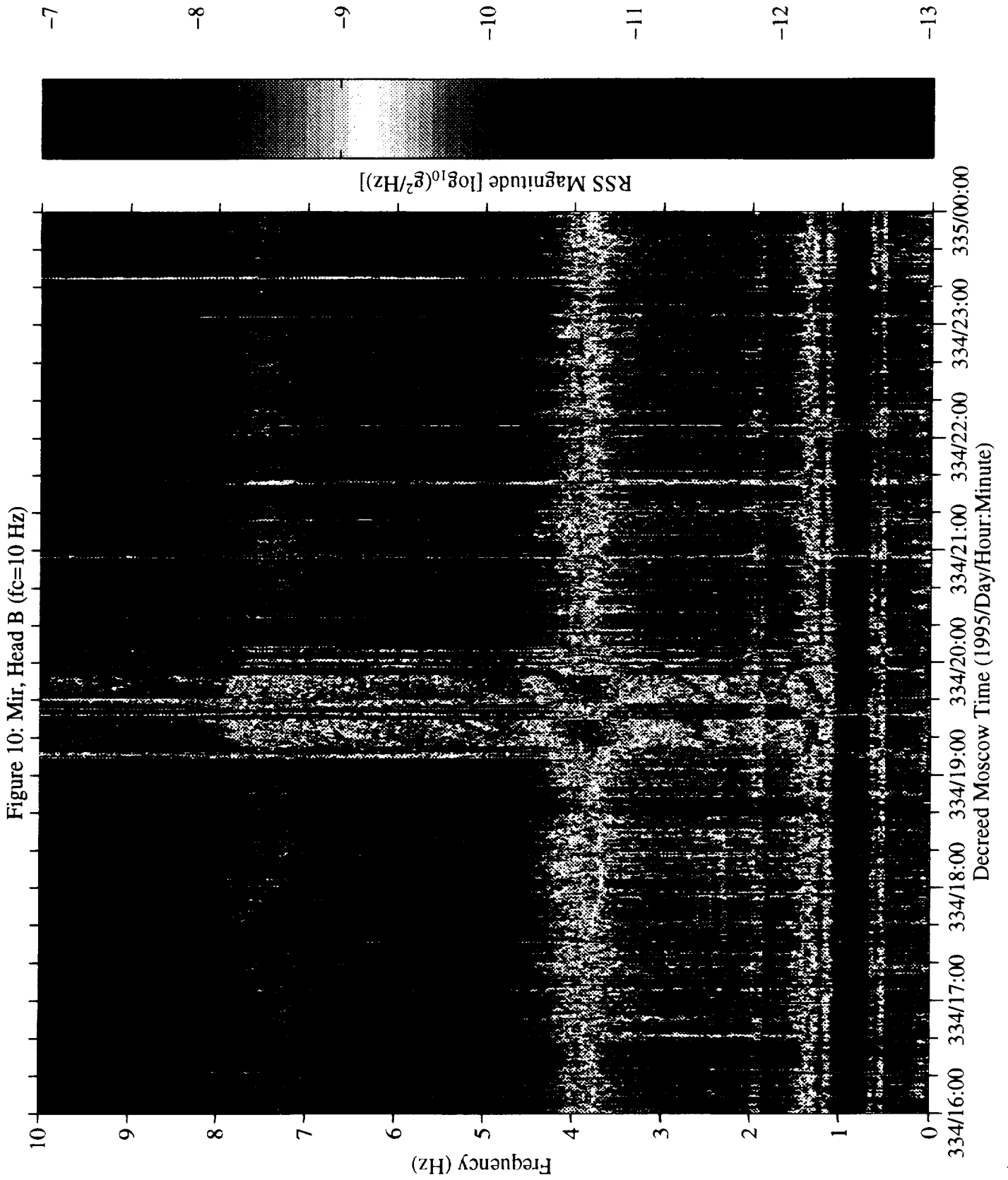
Figure 7b: Mir, Head B (fc=10 Hz): 10 Second Interval RMS

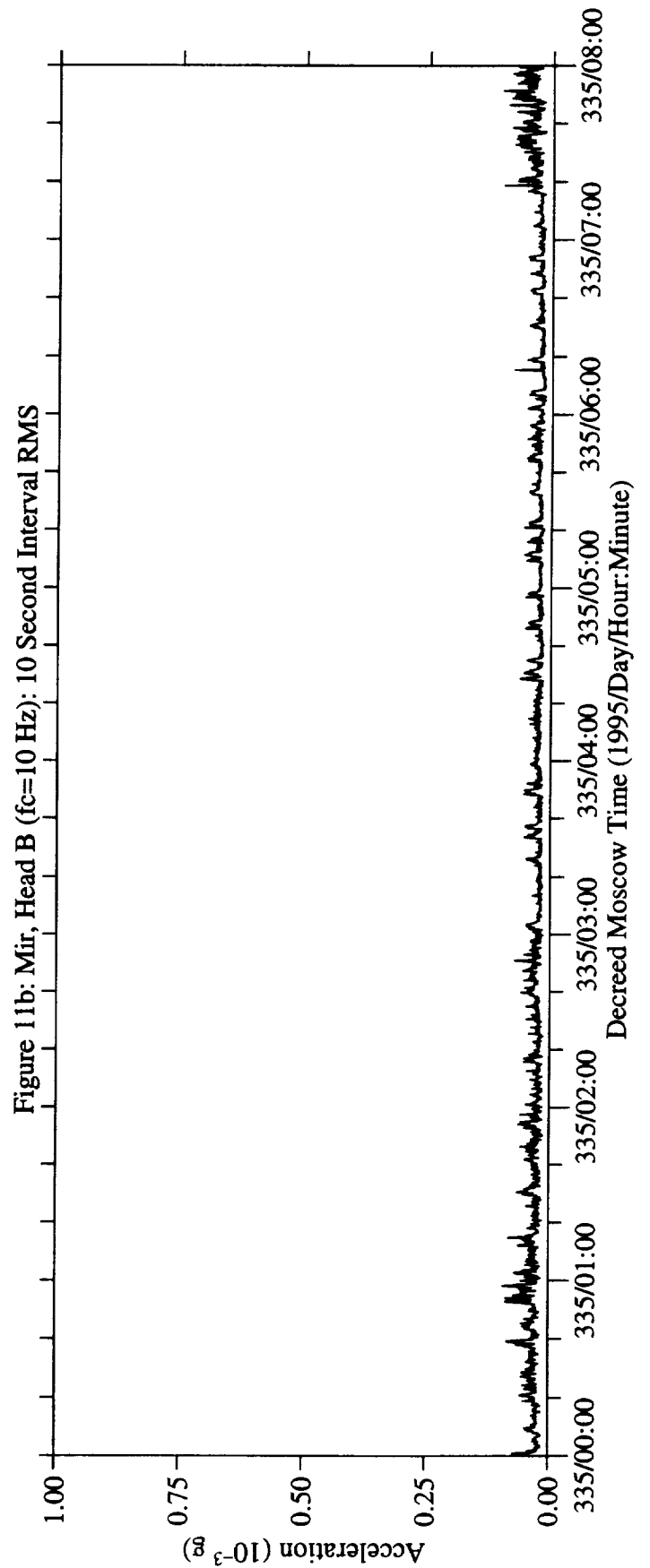
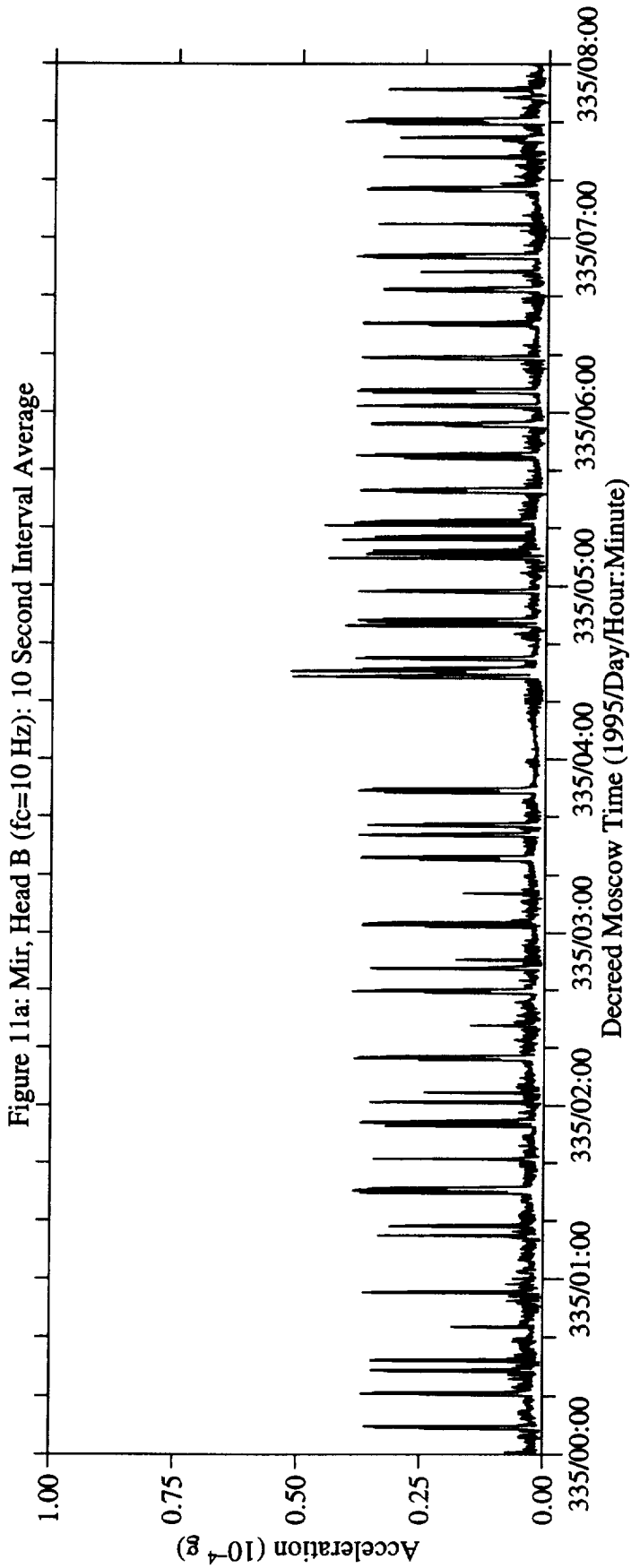


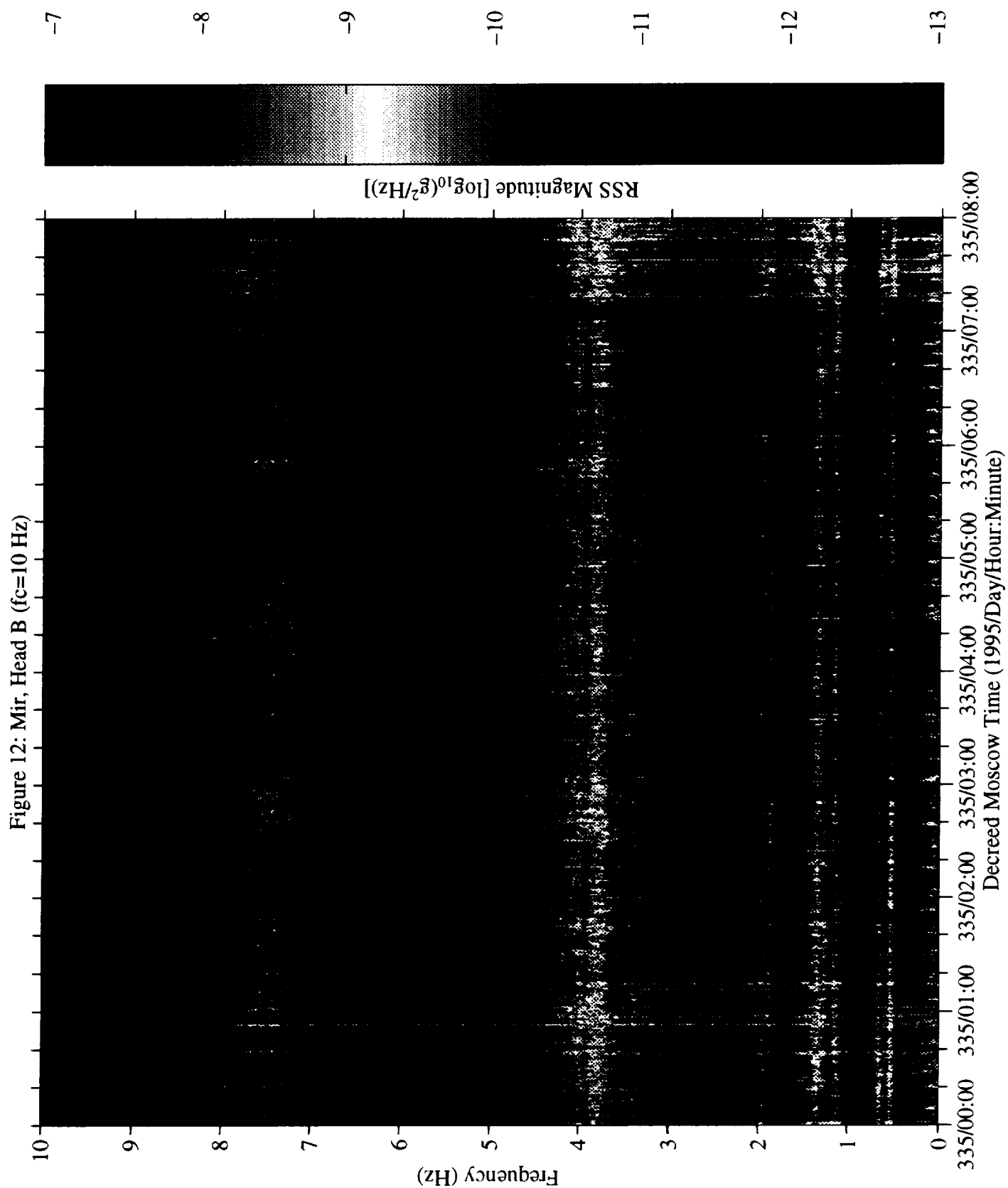


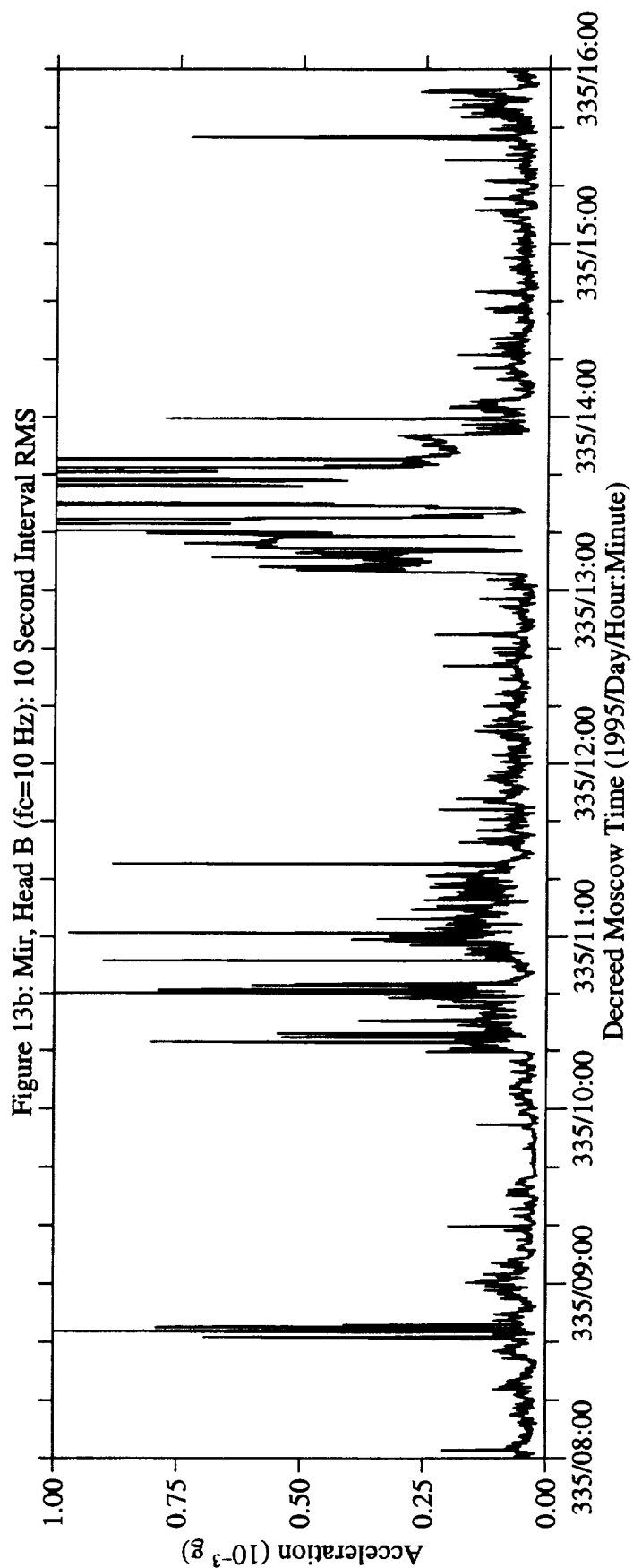
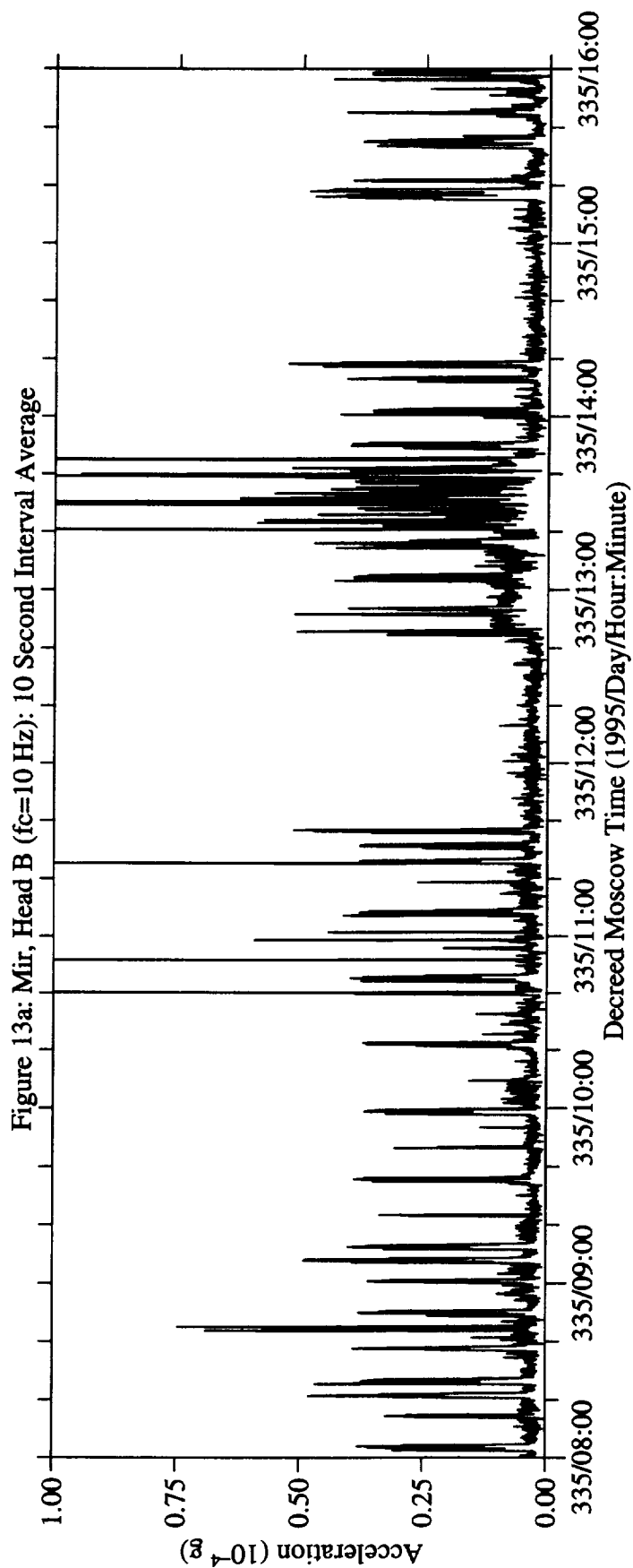


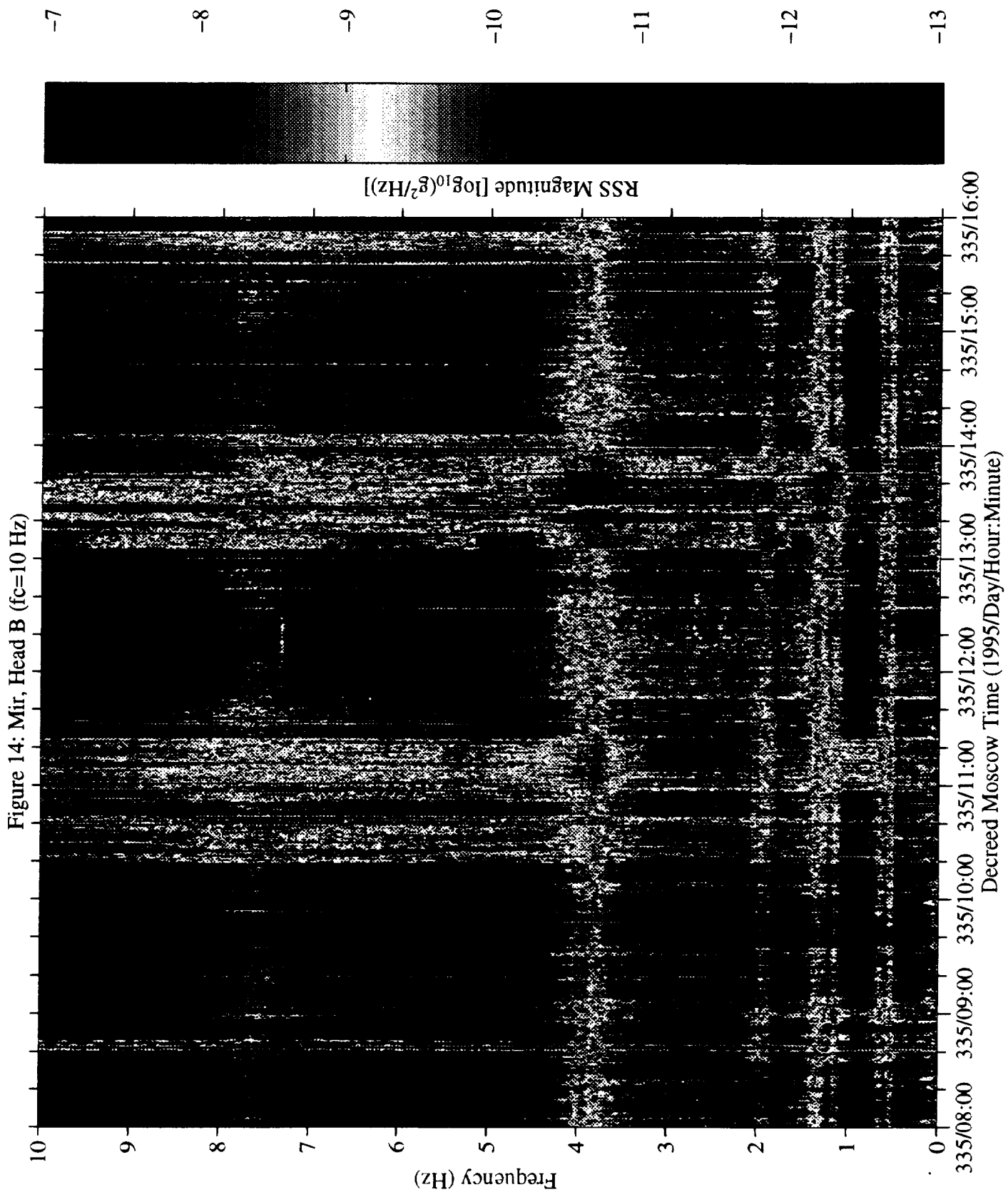


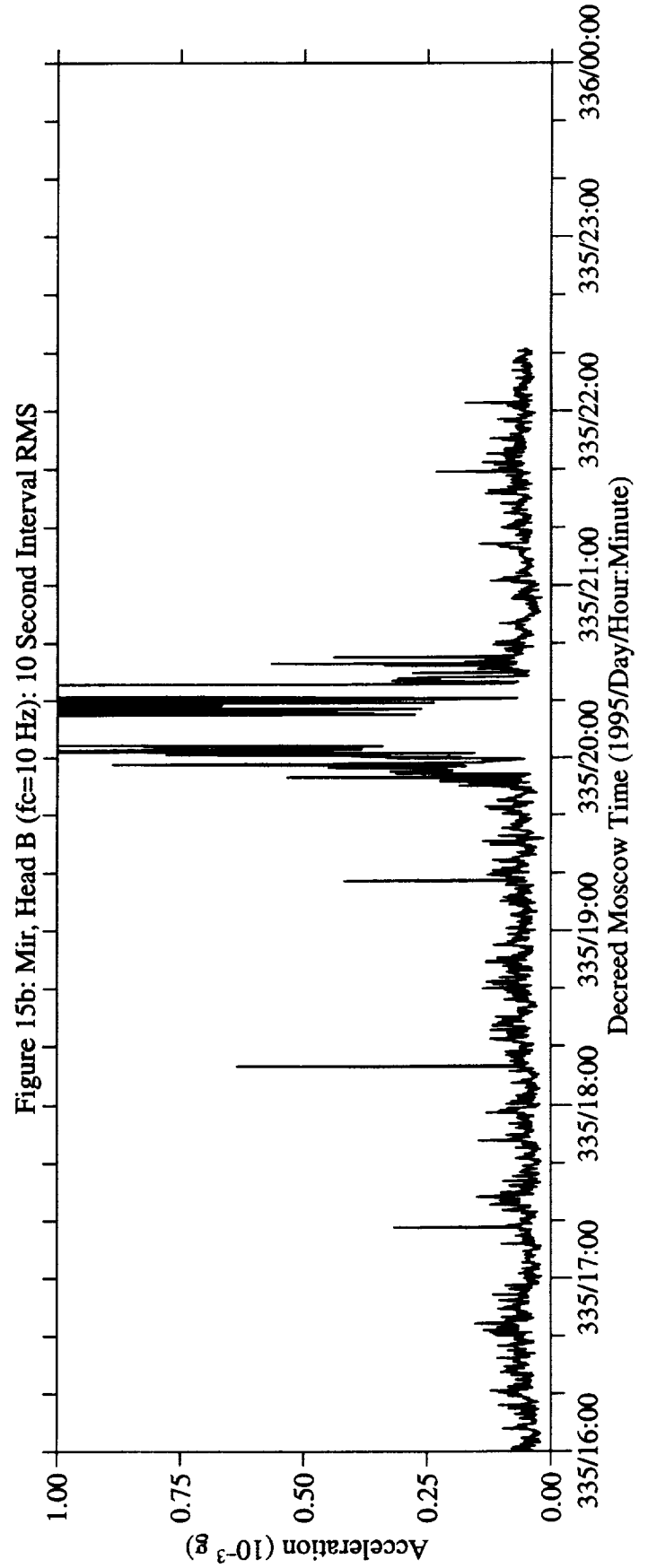
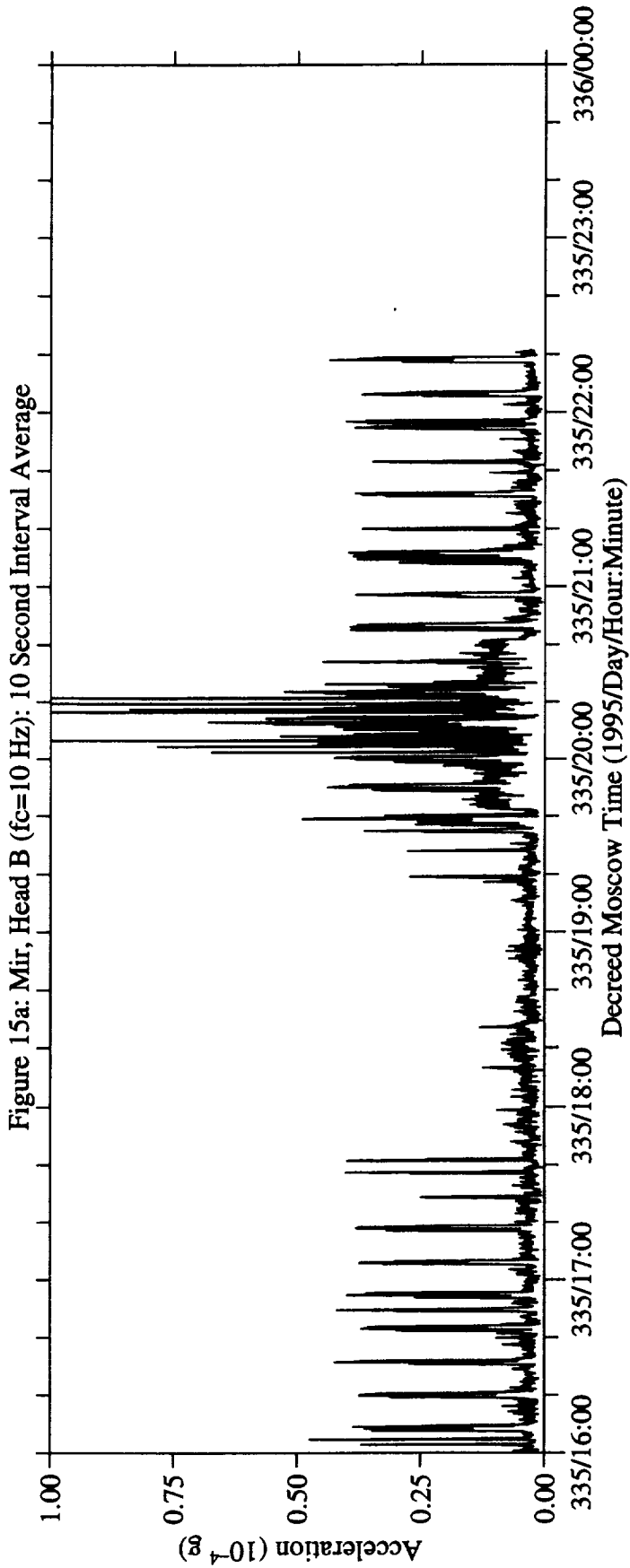


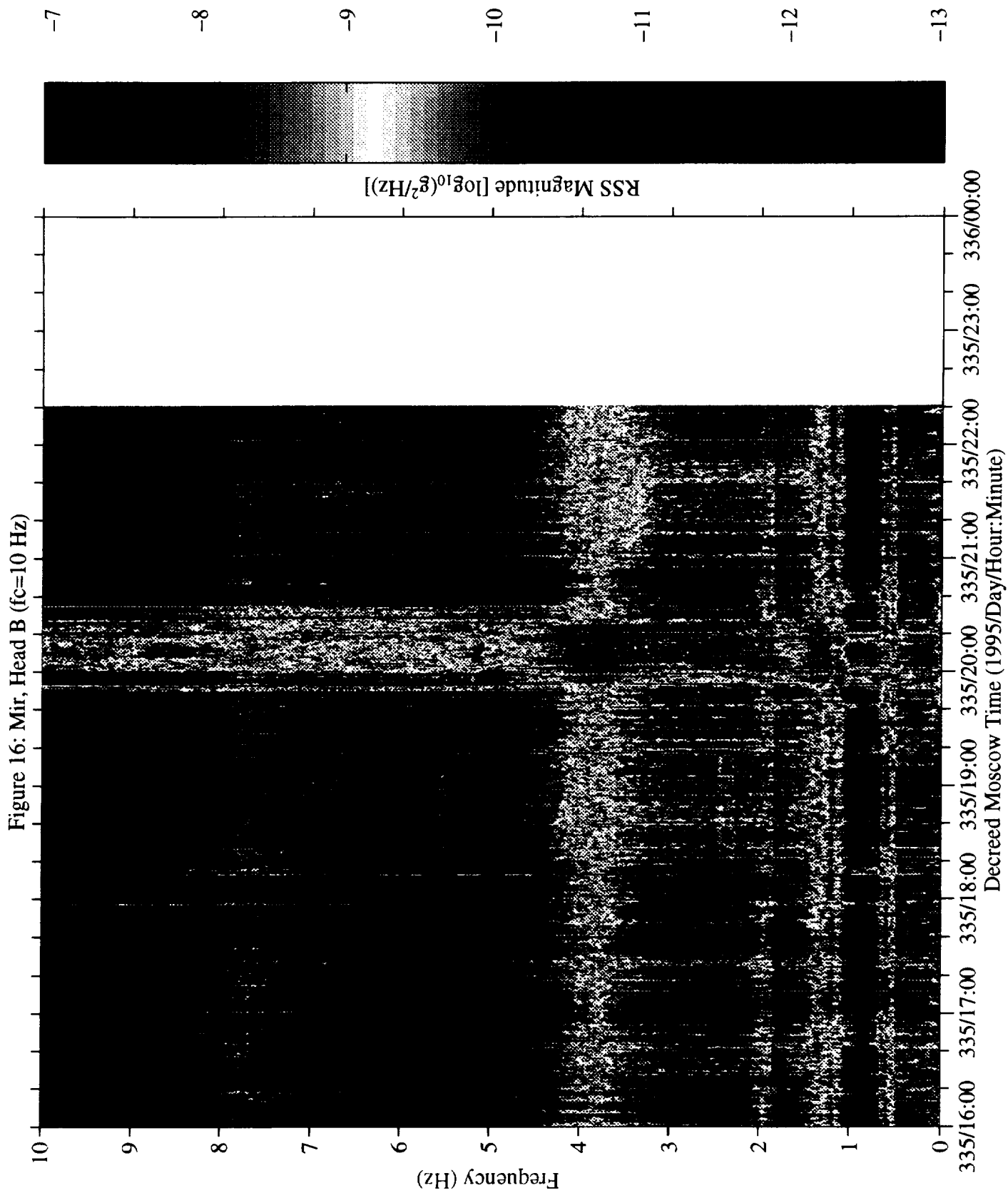












No data are available  
from 336/00:00:00 to 340/16:00:00



No data are available  
from 336/00:00:00 to 340/16:00:00

Figure 17a: Mir, Head B (fc=10 Hz): 10 Second Interval Average

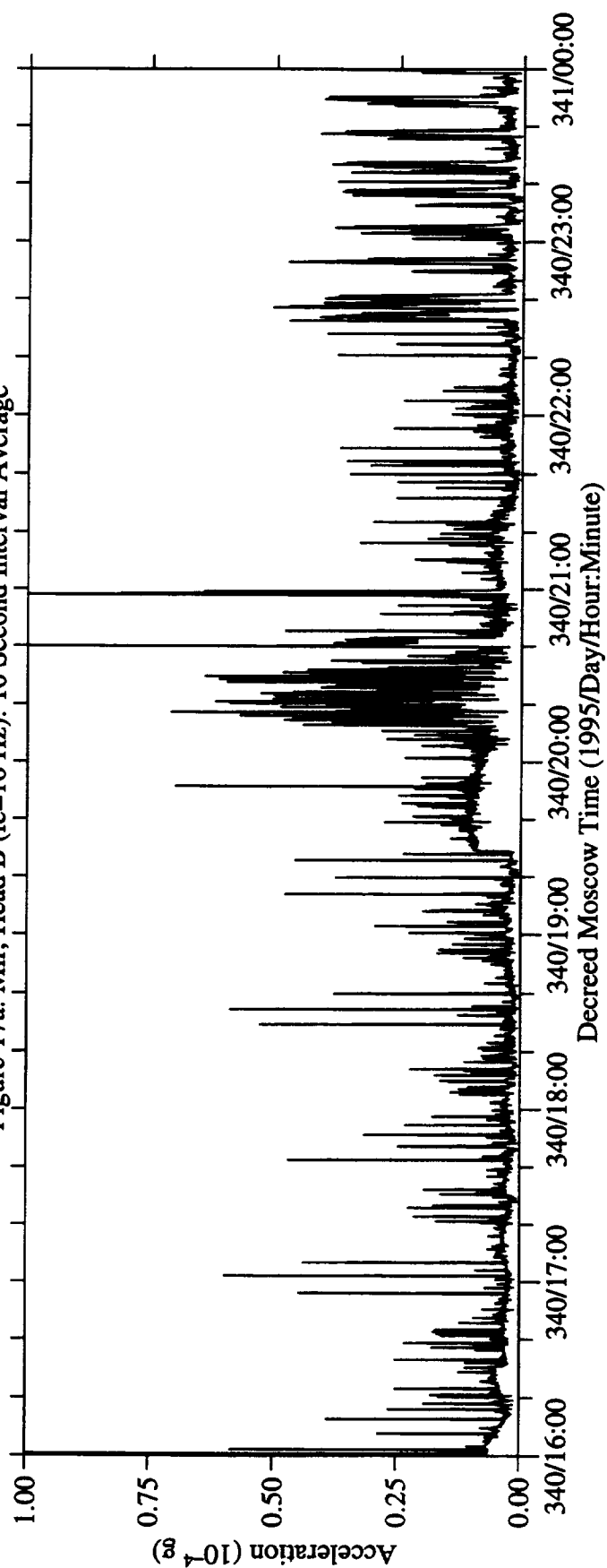
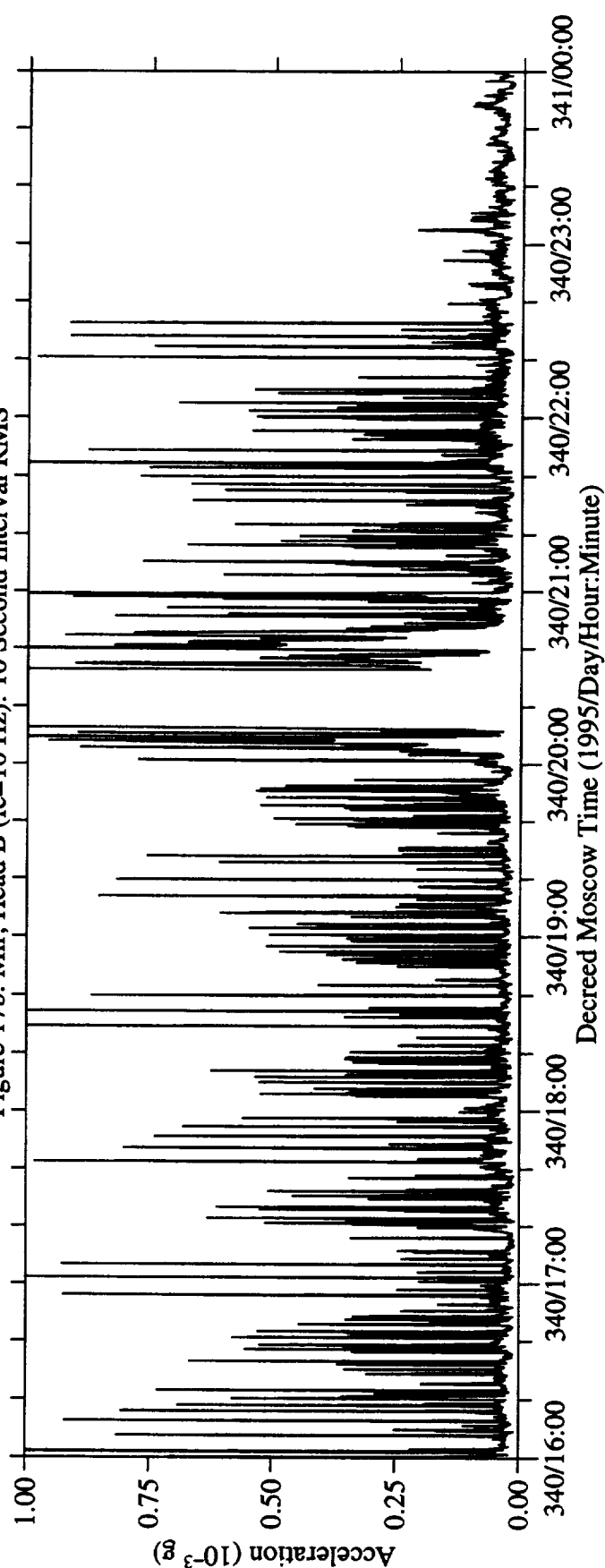


Figure 17b: Mir, Head B (fc=10 Hz): 10 Second Interval RMS



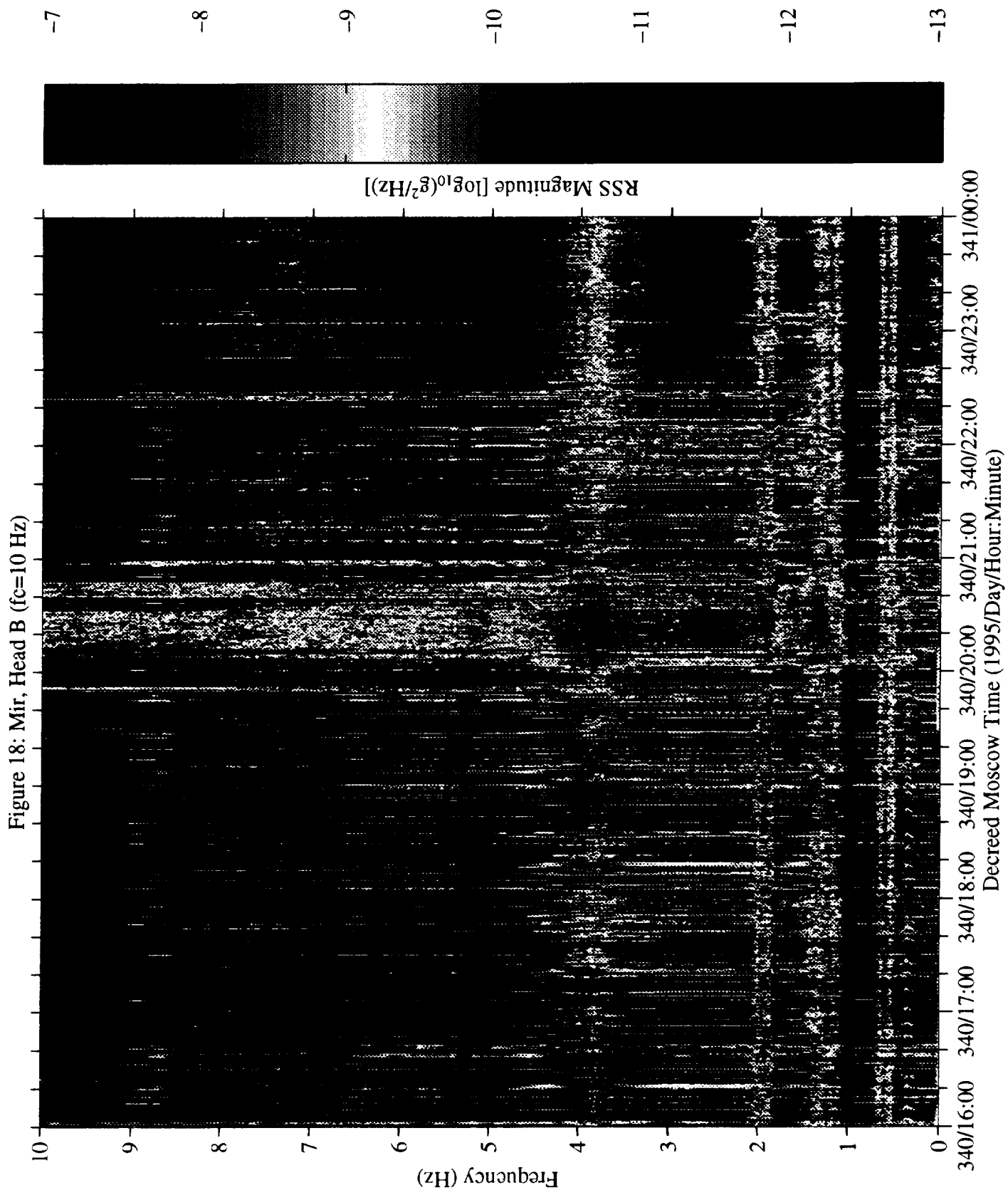


Figure 19a: Mir, Head B (fc=10 Hz): 10 Second Interval Average

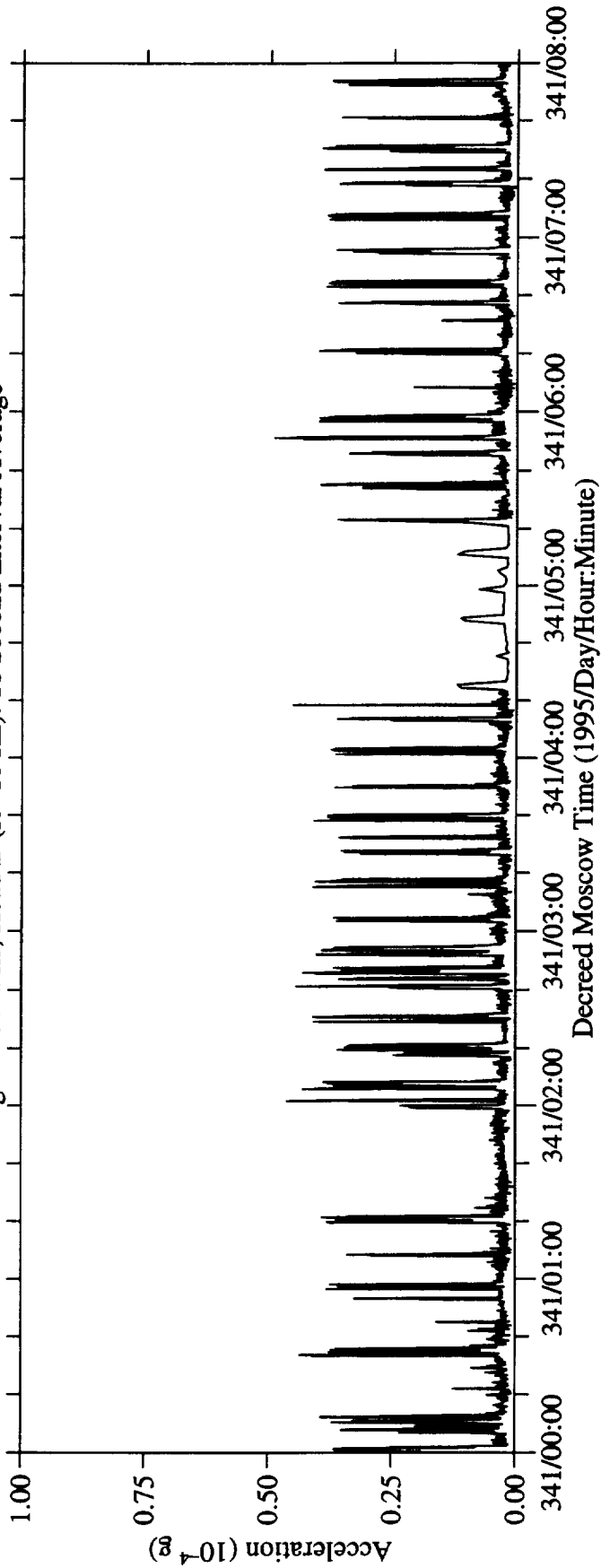
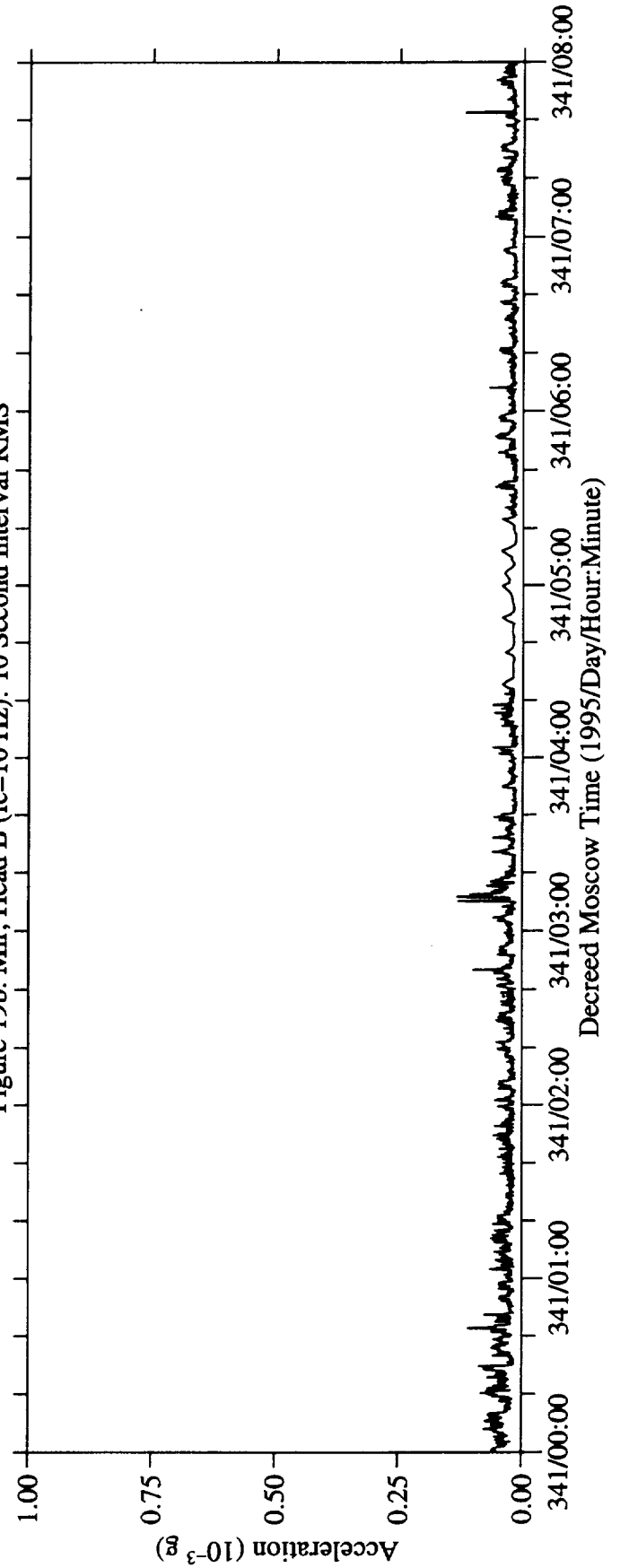
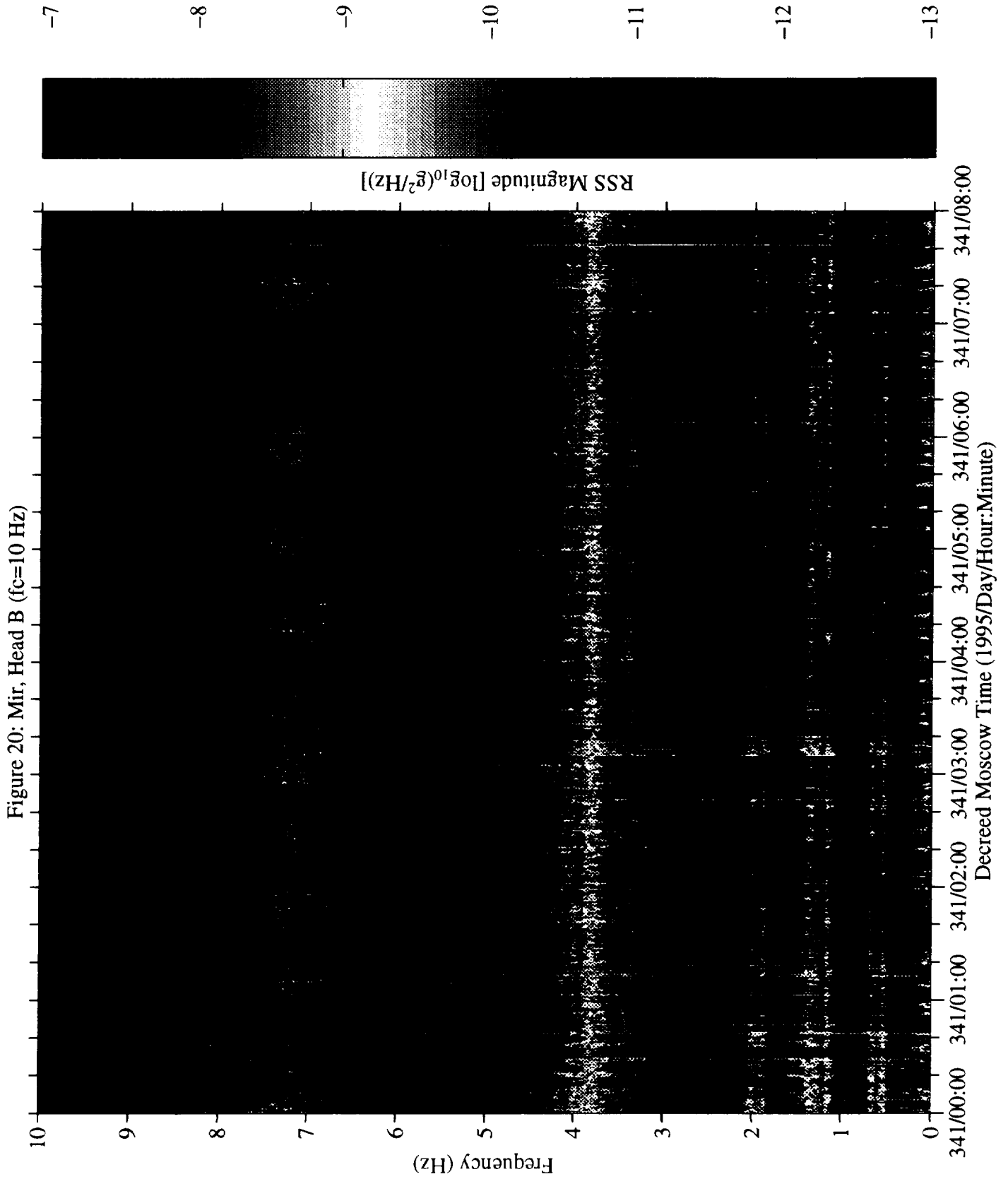
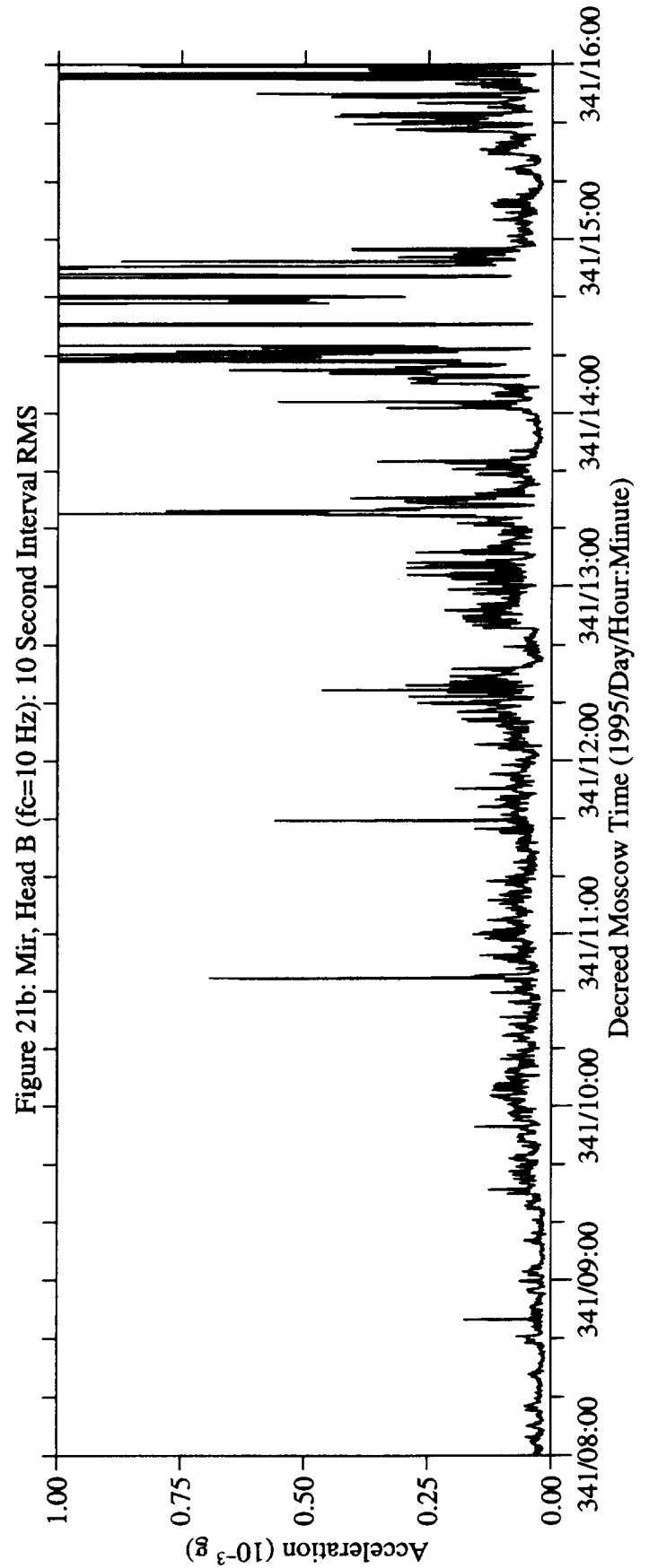
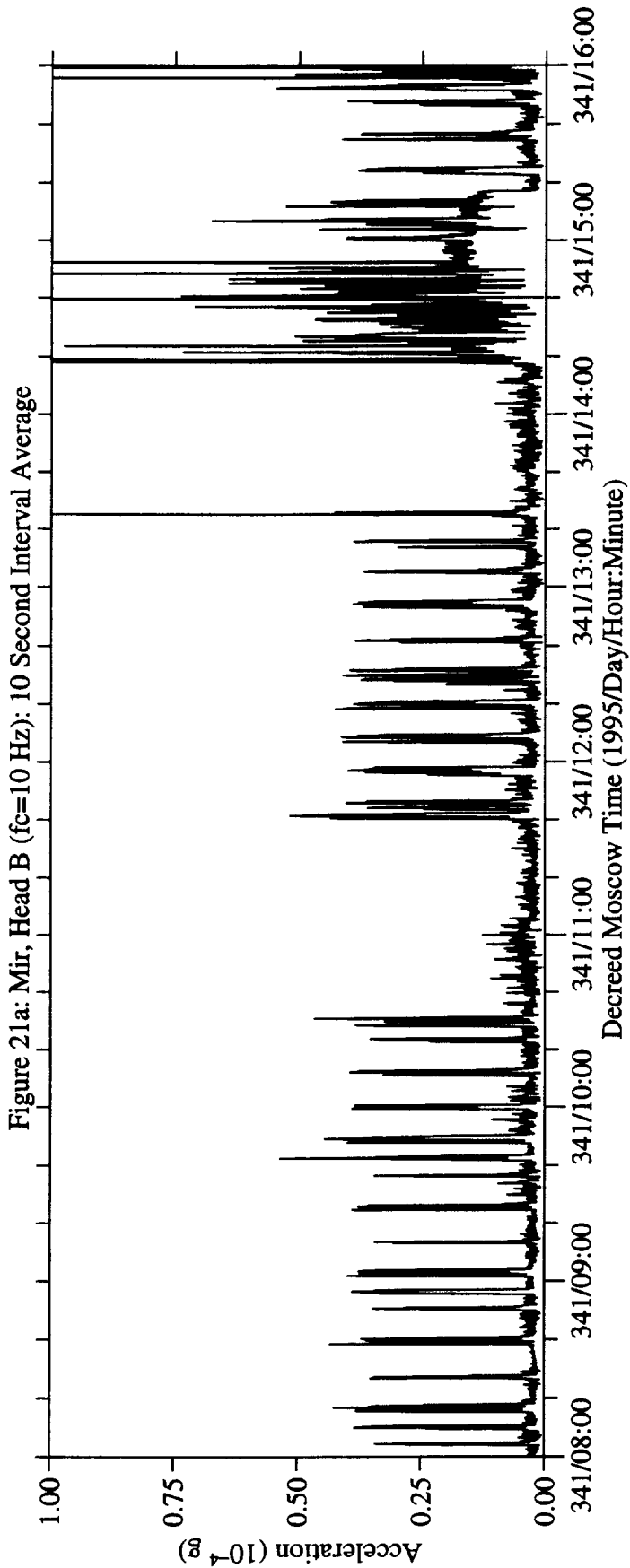


Figure 19b: Mir, Head B (fc=10 Hz): 10 Second Interval RMS







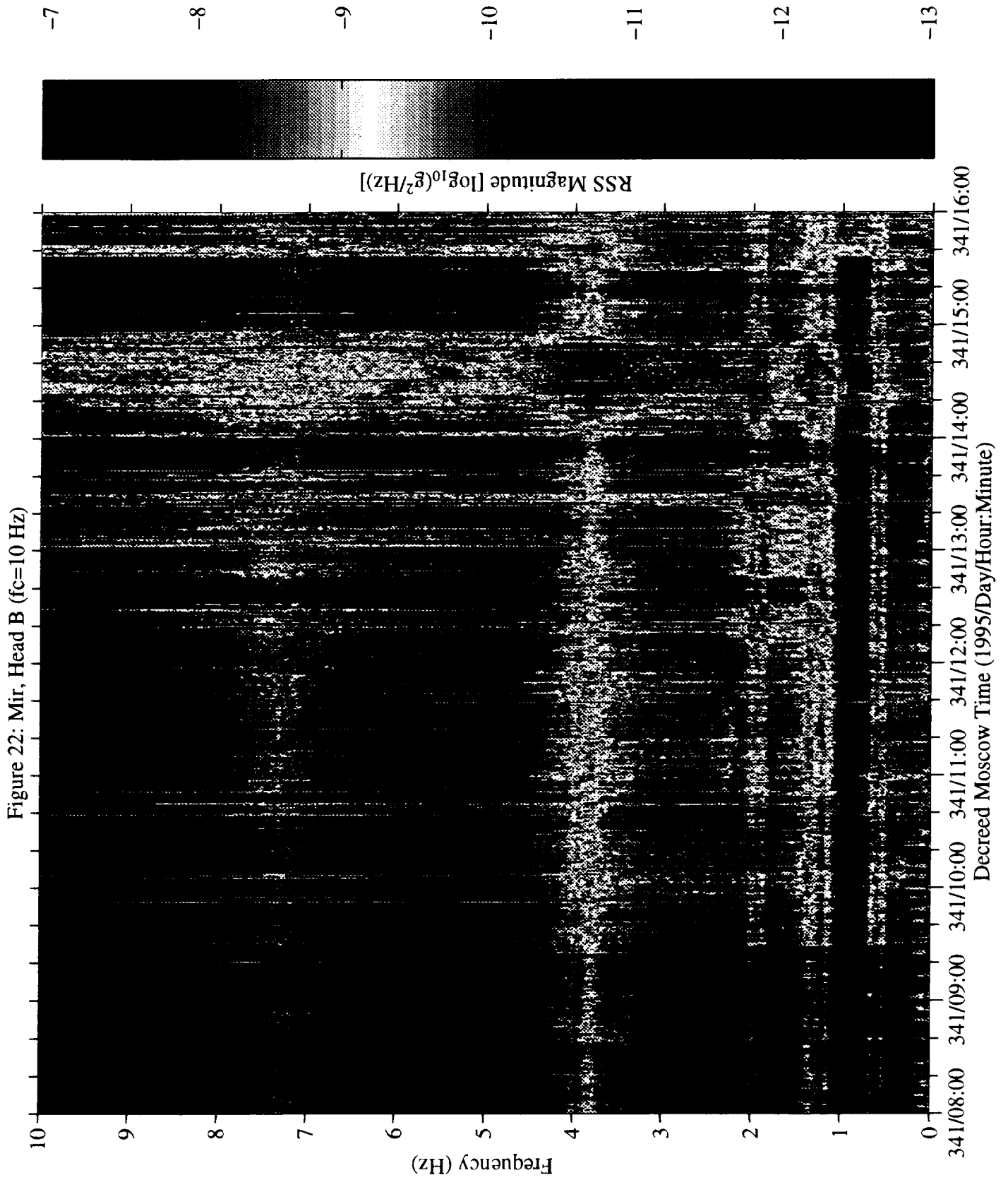


Figure 23a: Mir, Head B (fc=10 Hz): 10 Second Interval Average

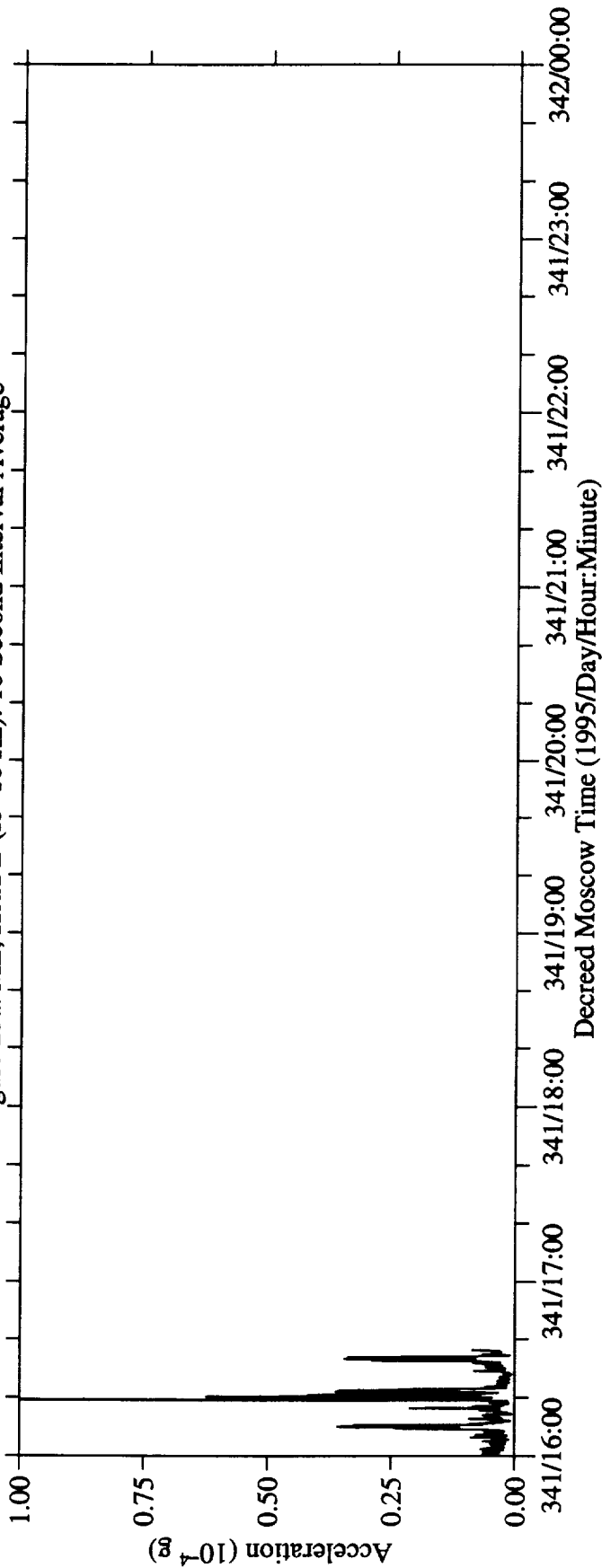
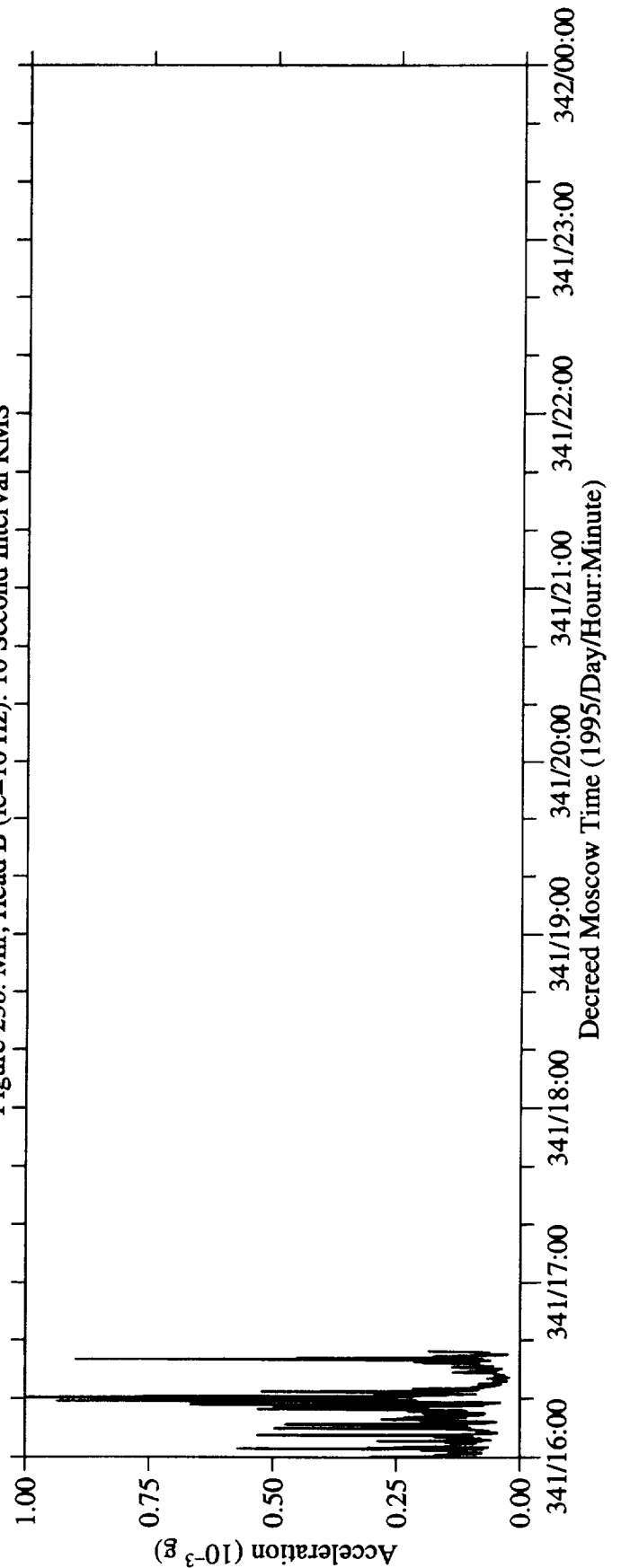
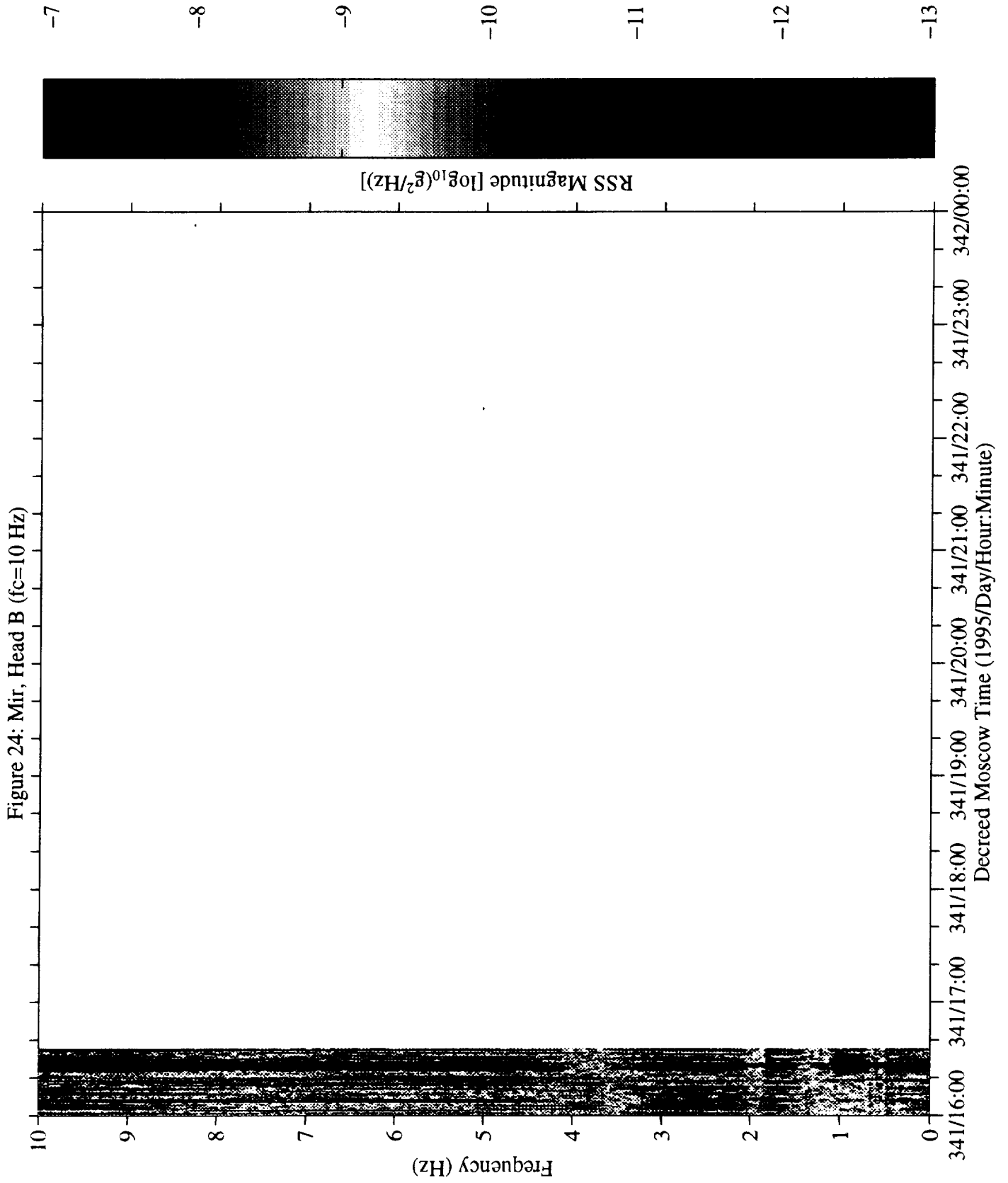


Figure 23b: Mir, Head B (fc=10 Hz): 10 Second Interval RMS

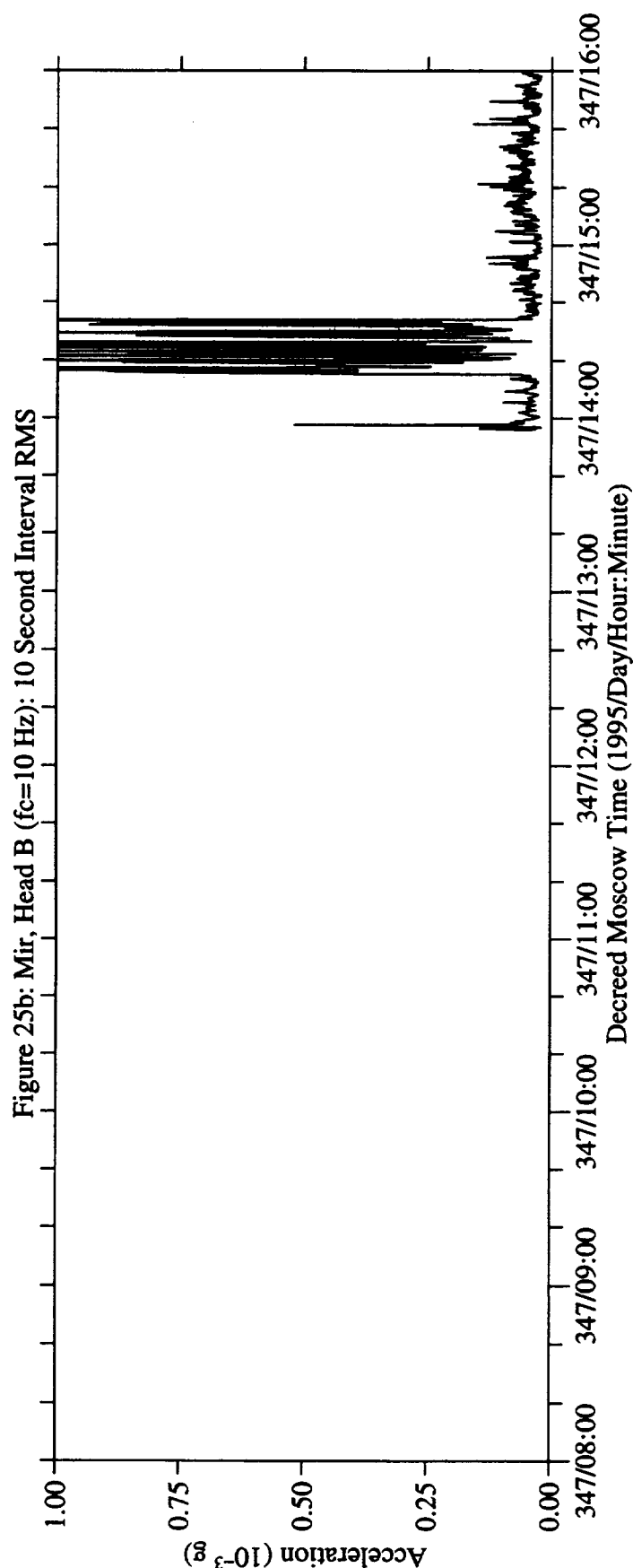
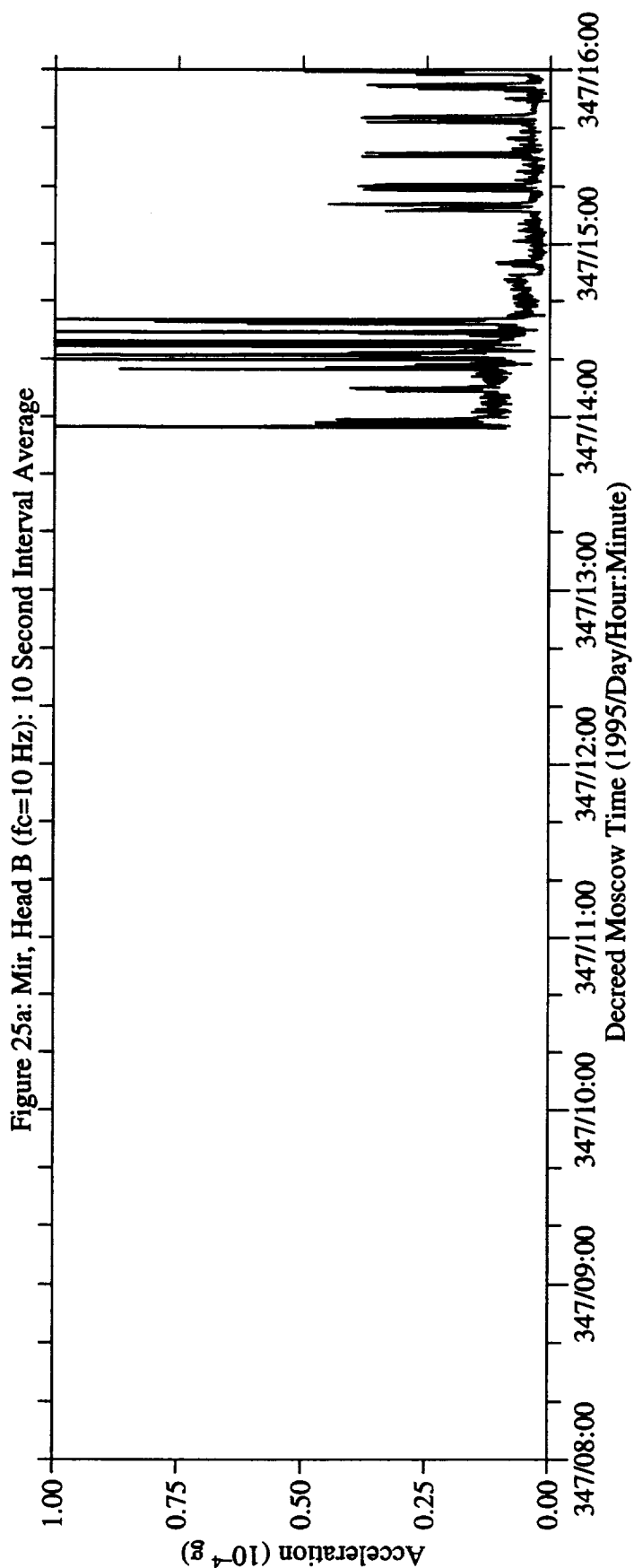


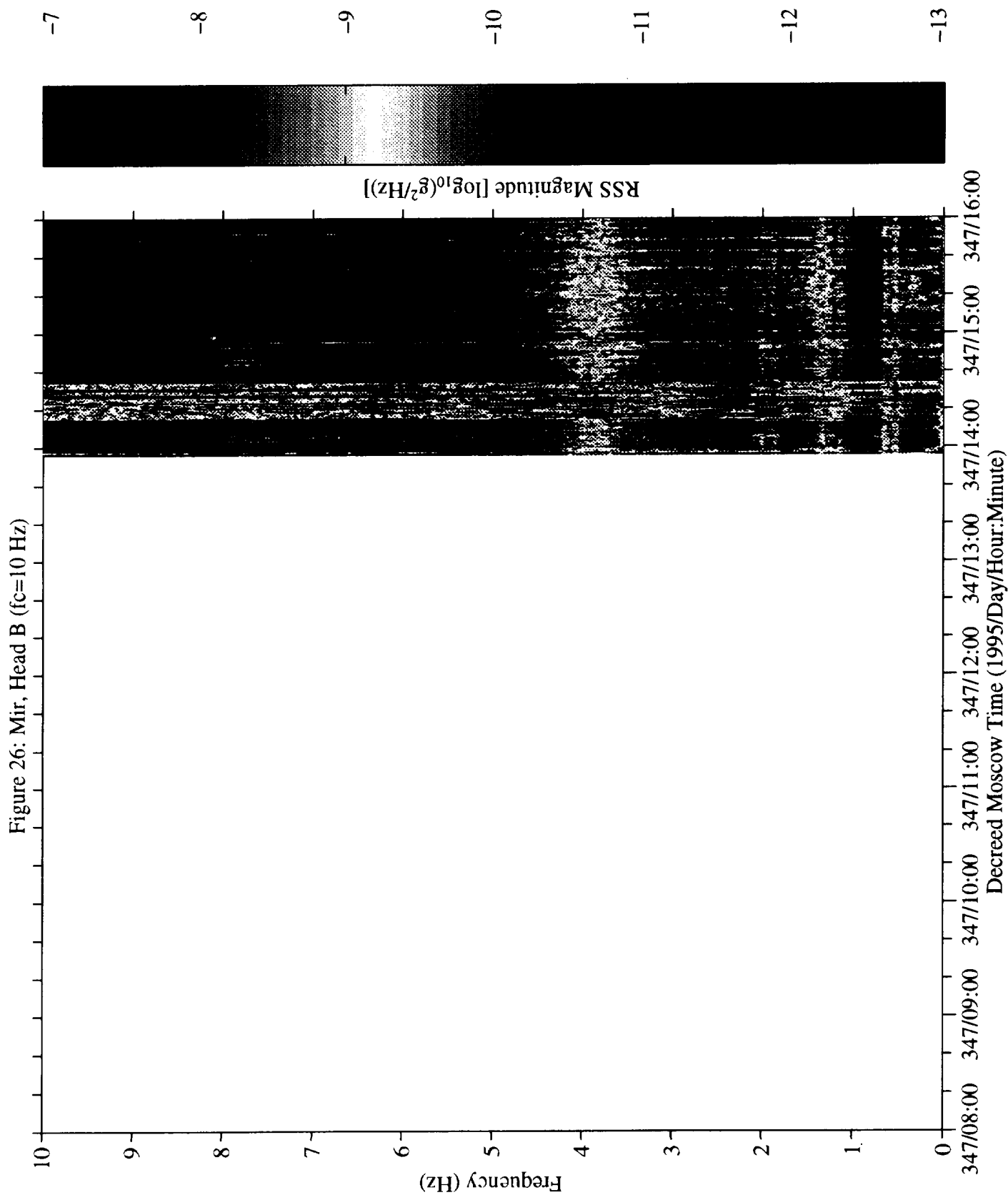


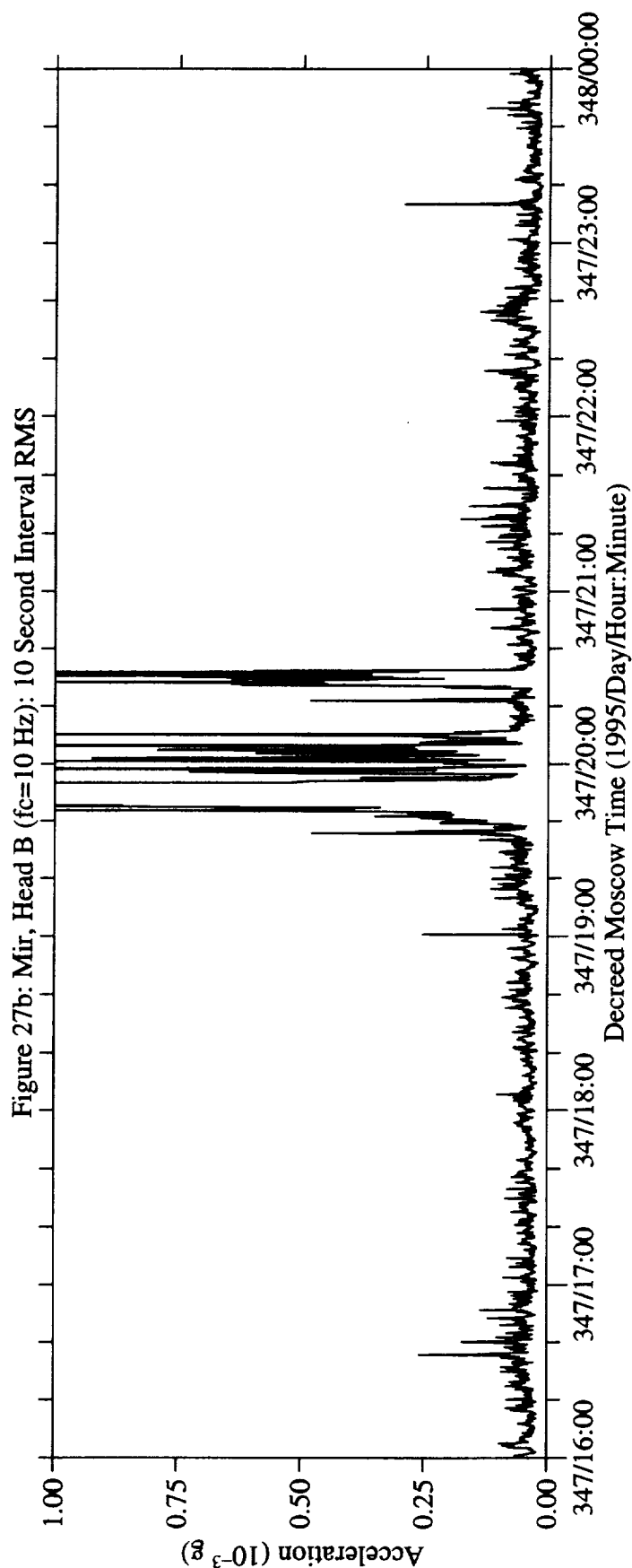
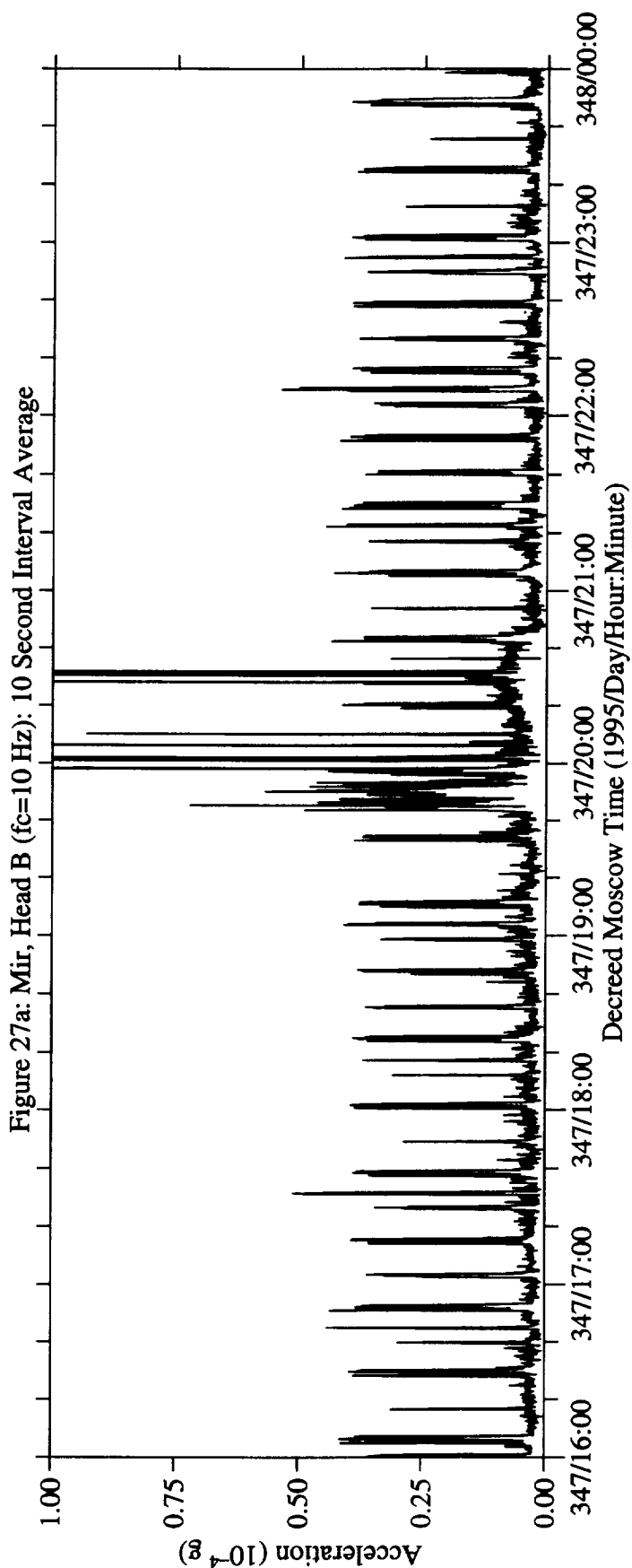


No data are available  
from 342/00:00:00 to 347/08:00:00

No data are available  
from 342/00:00:00 to 347/08:00:00







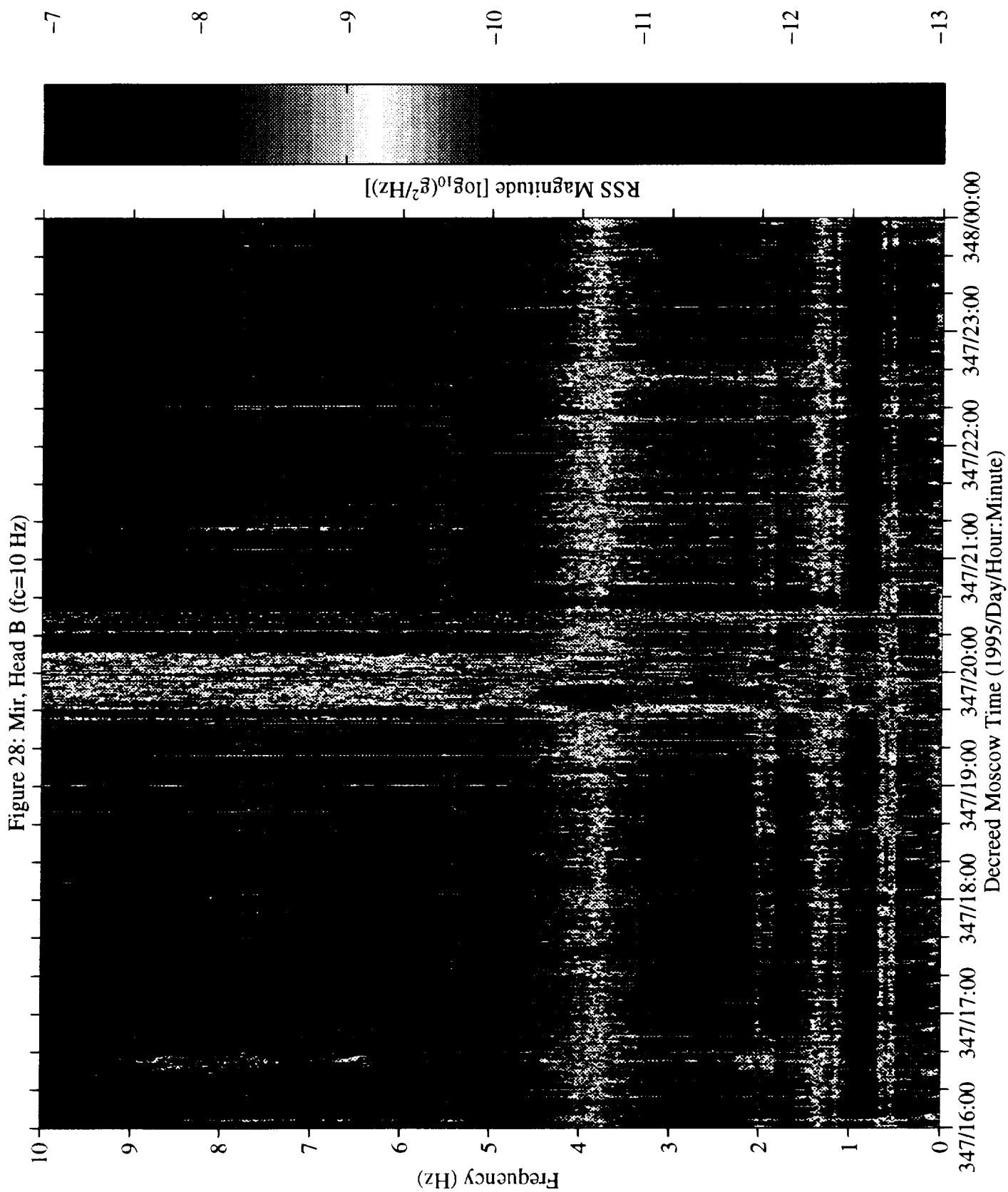


Figure 29a: Mir, Head B (fc=10 Hz): 10 Second Interval Average

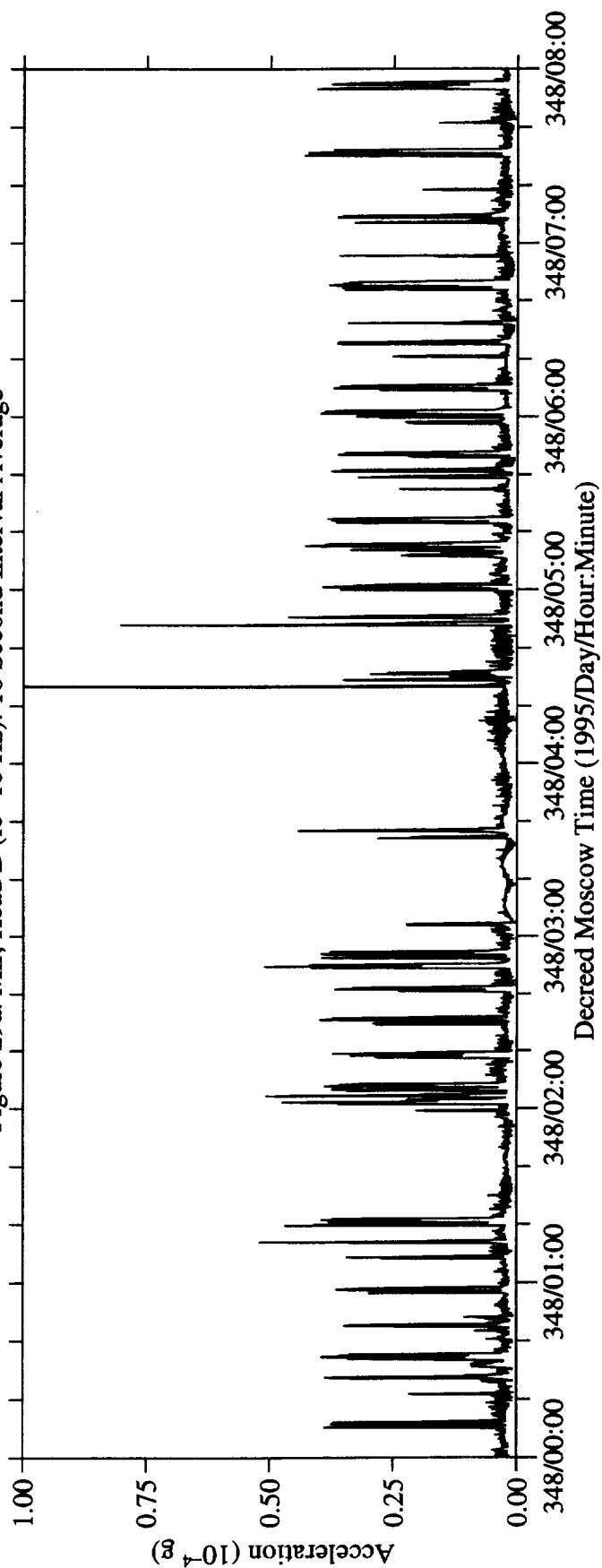
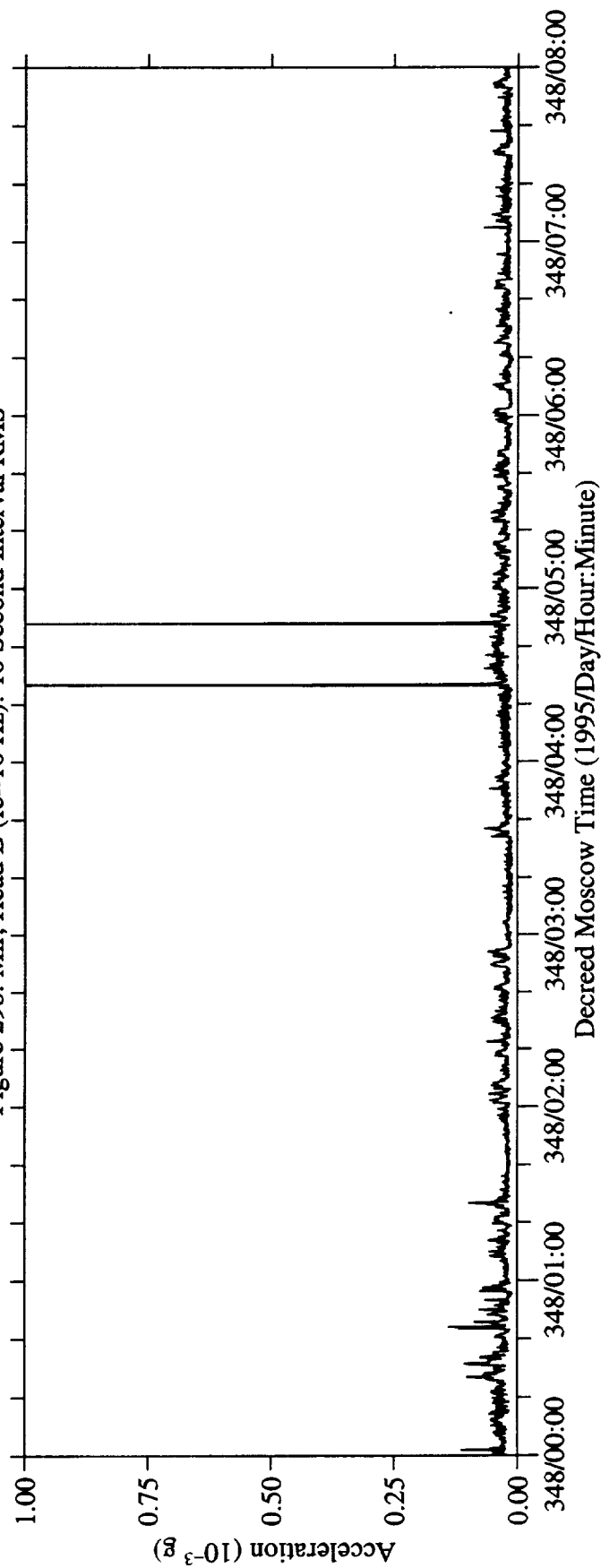
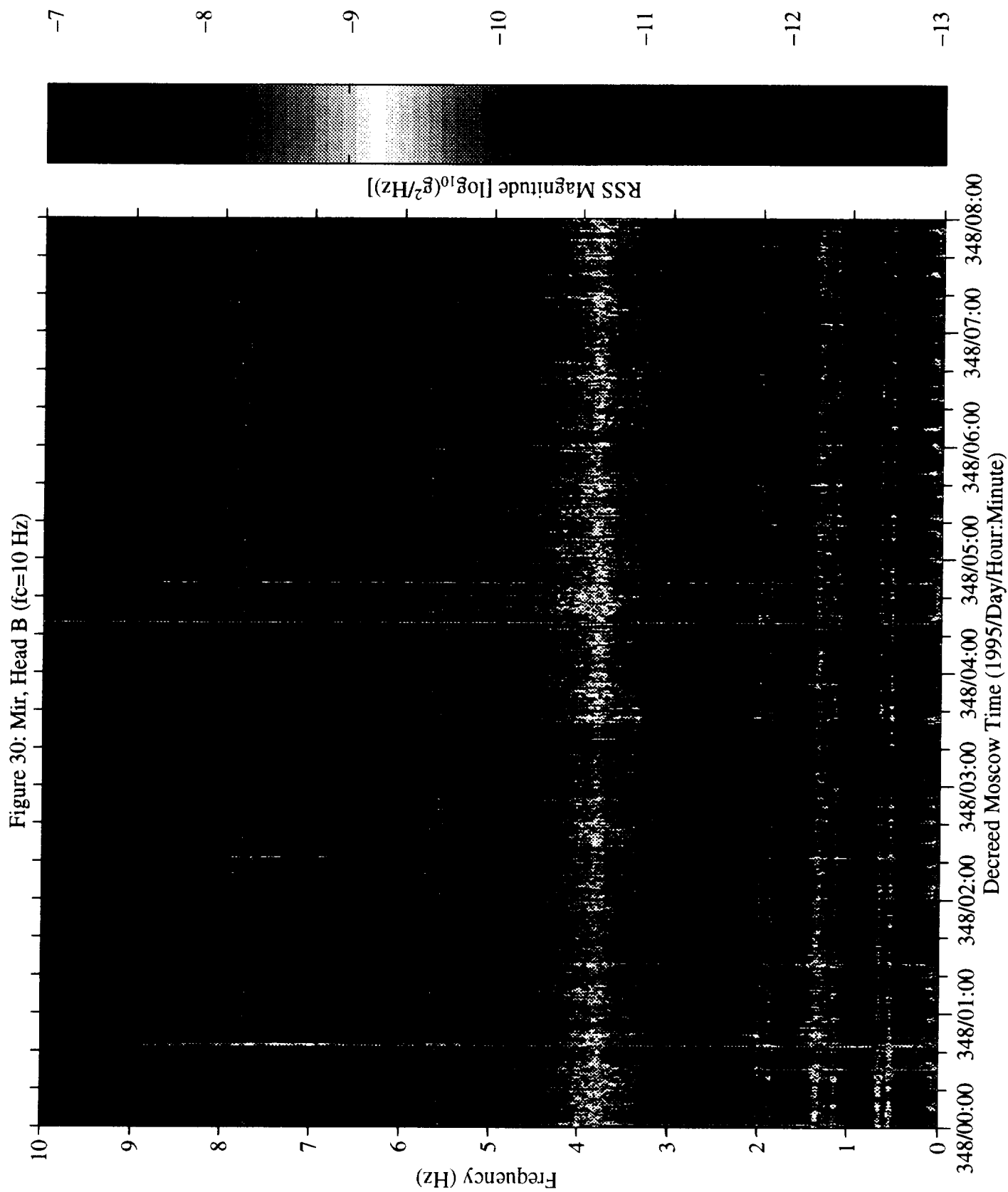
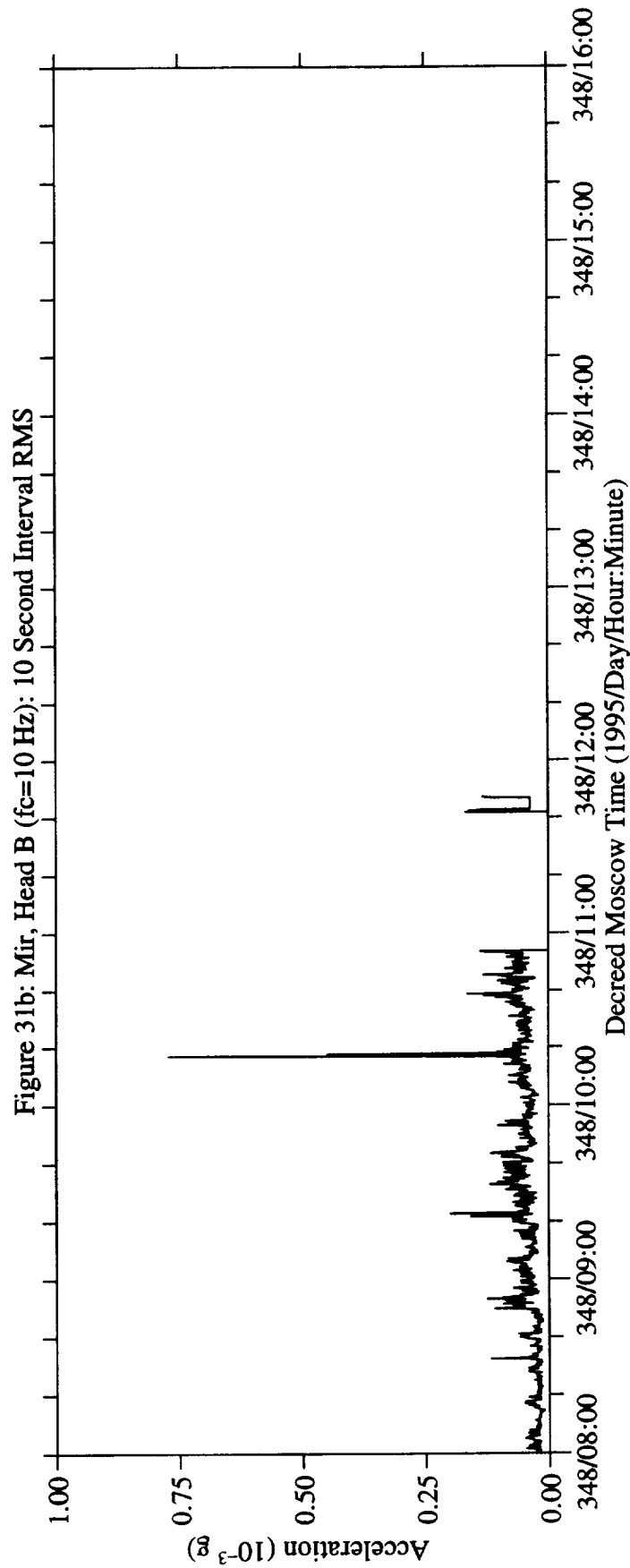
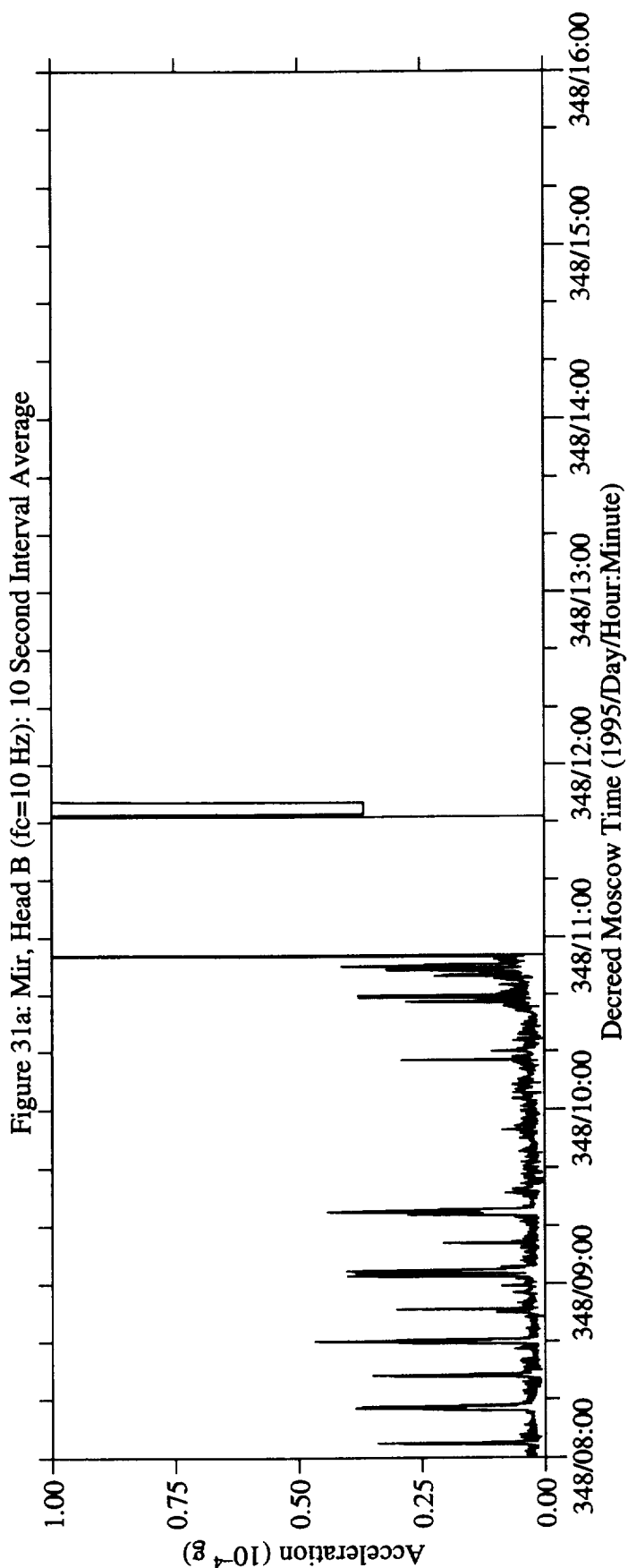


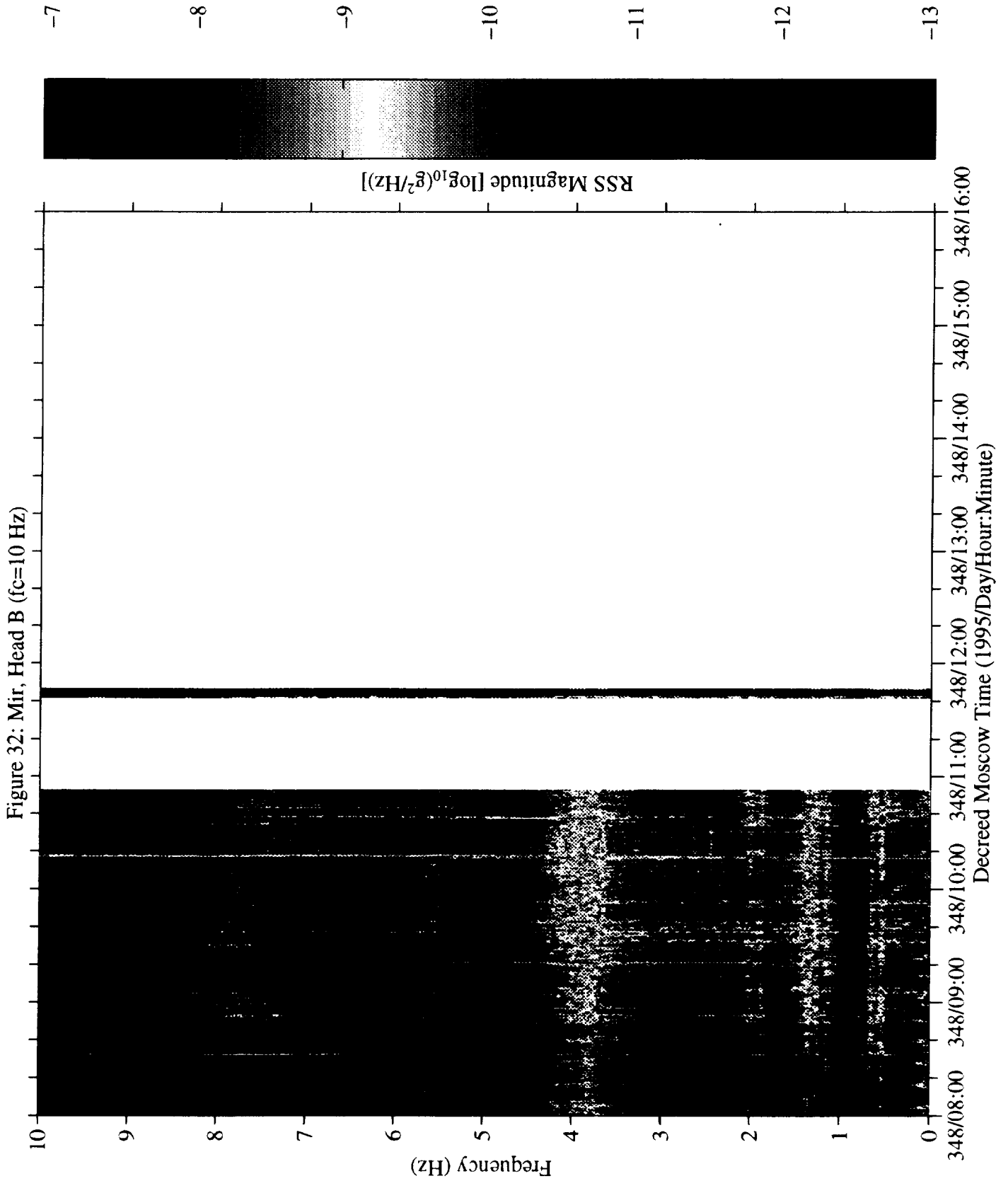
Figure 29b: Mir, Head B (fc=10 Hz): 10 Second Interval RMS











No data are available  
from 348/16:00:00 to 354/08:00:00

No data are available  
from 348/16:00:00 to 354/08:00:00

Figure 33a: Mir, Head B (fc=10 Hz): 10 Second Interval Average

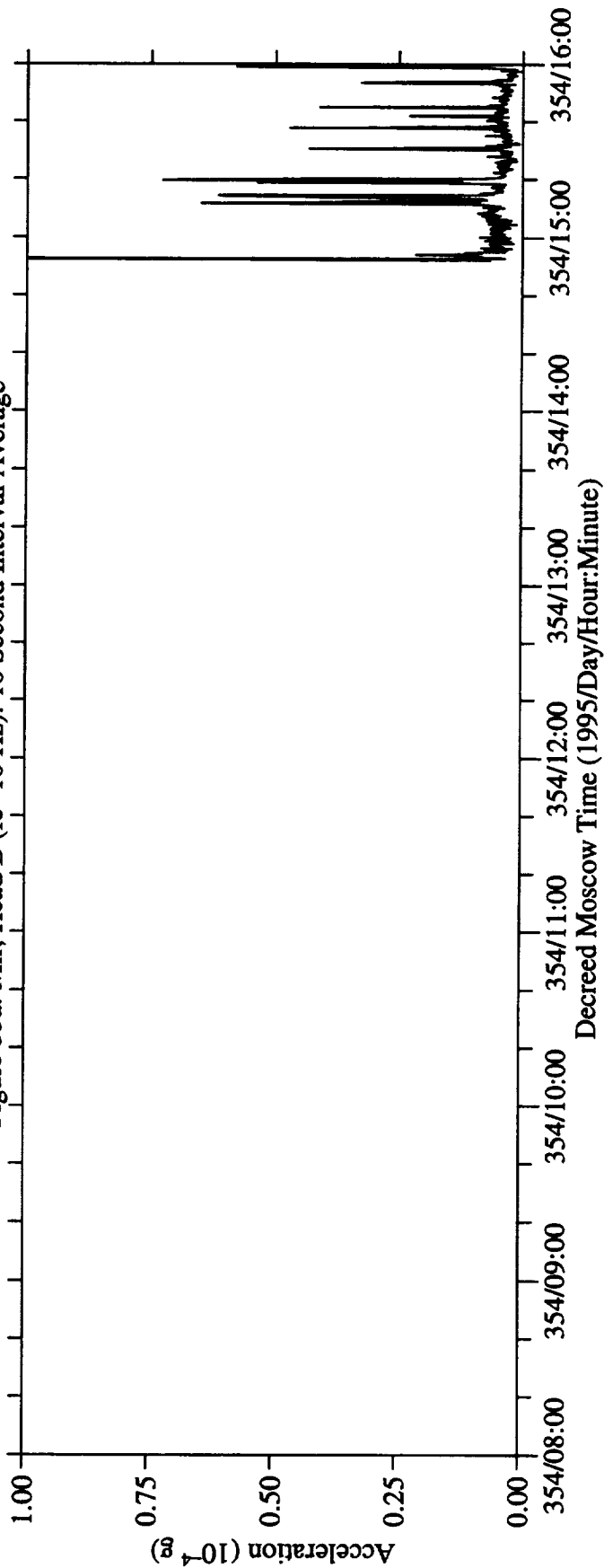
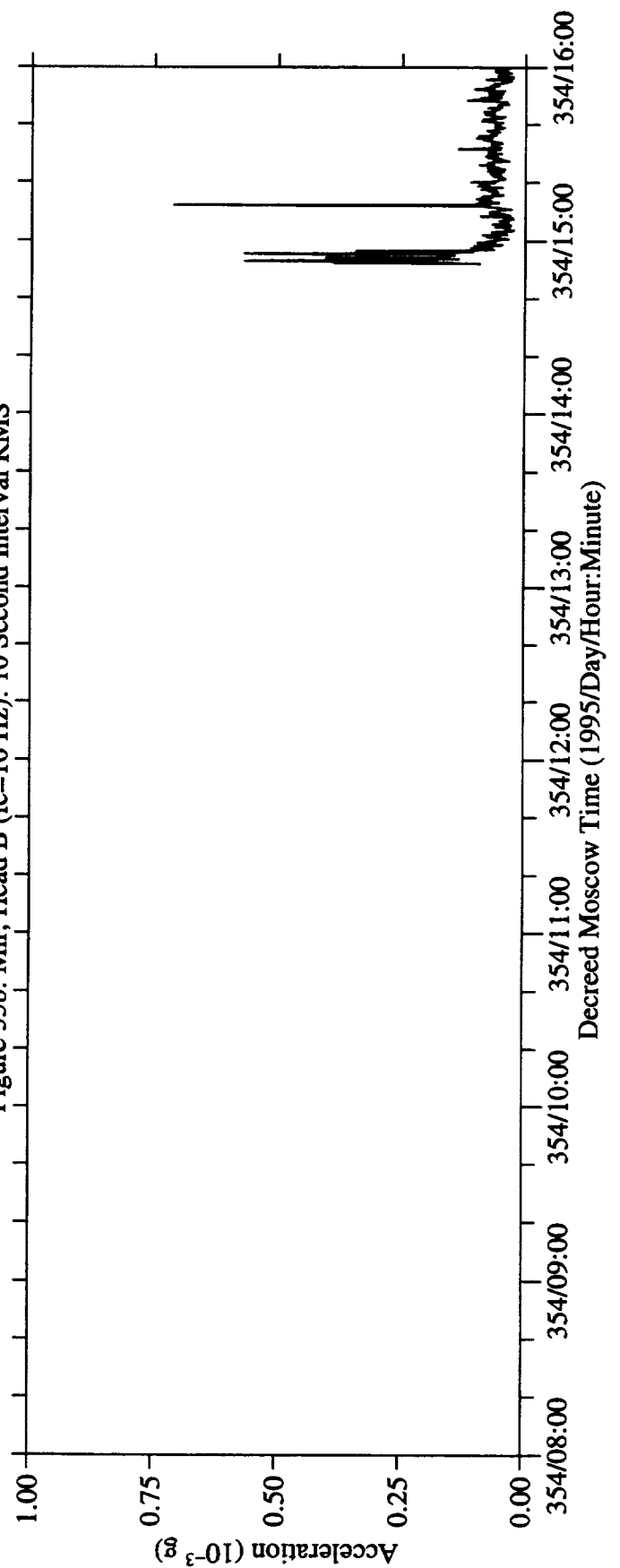
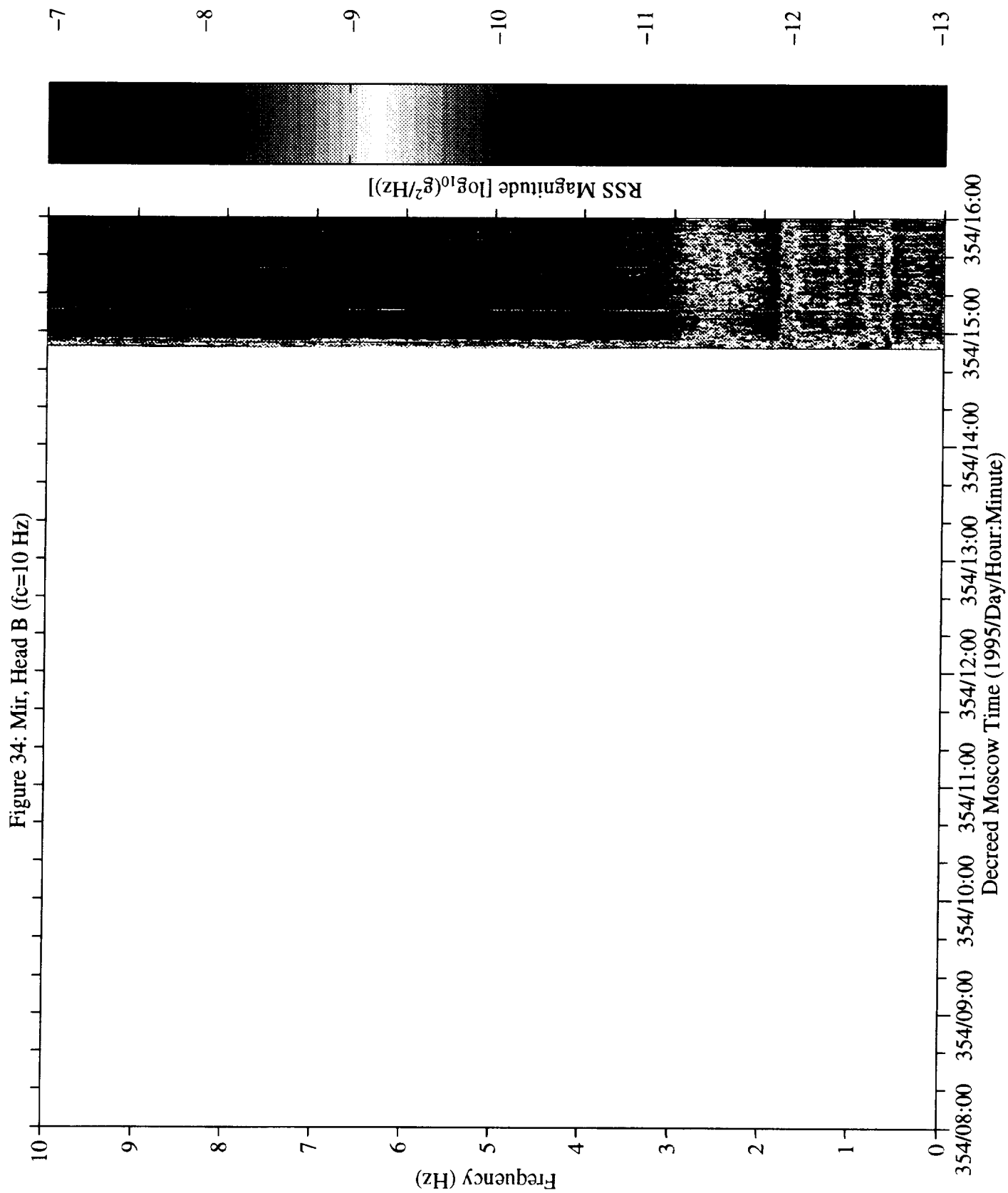
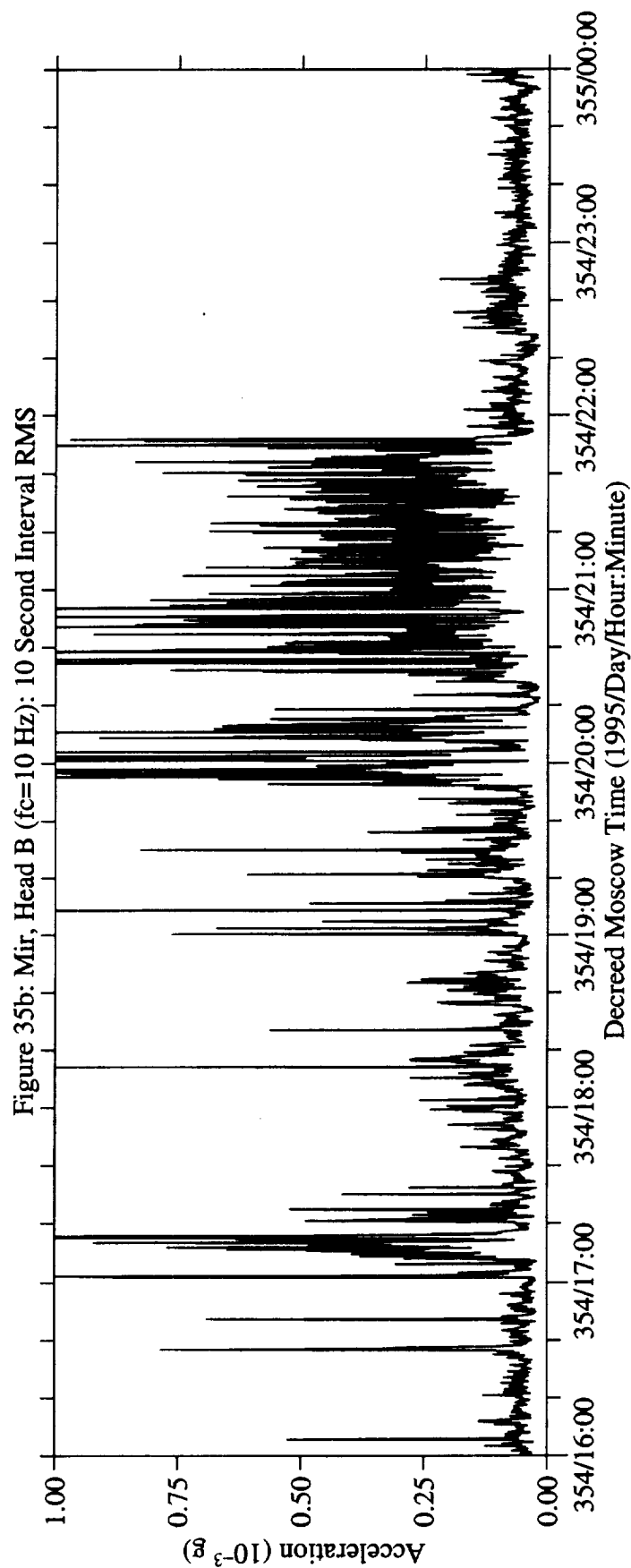
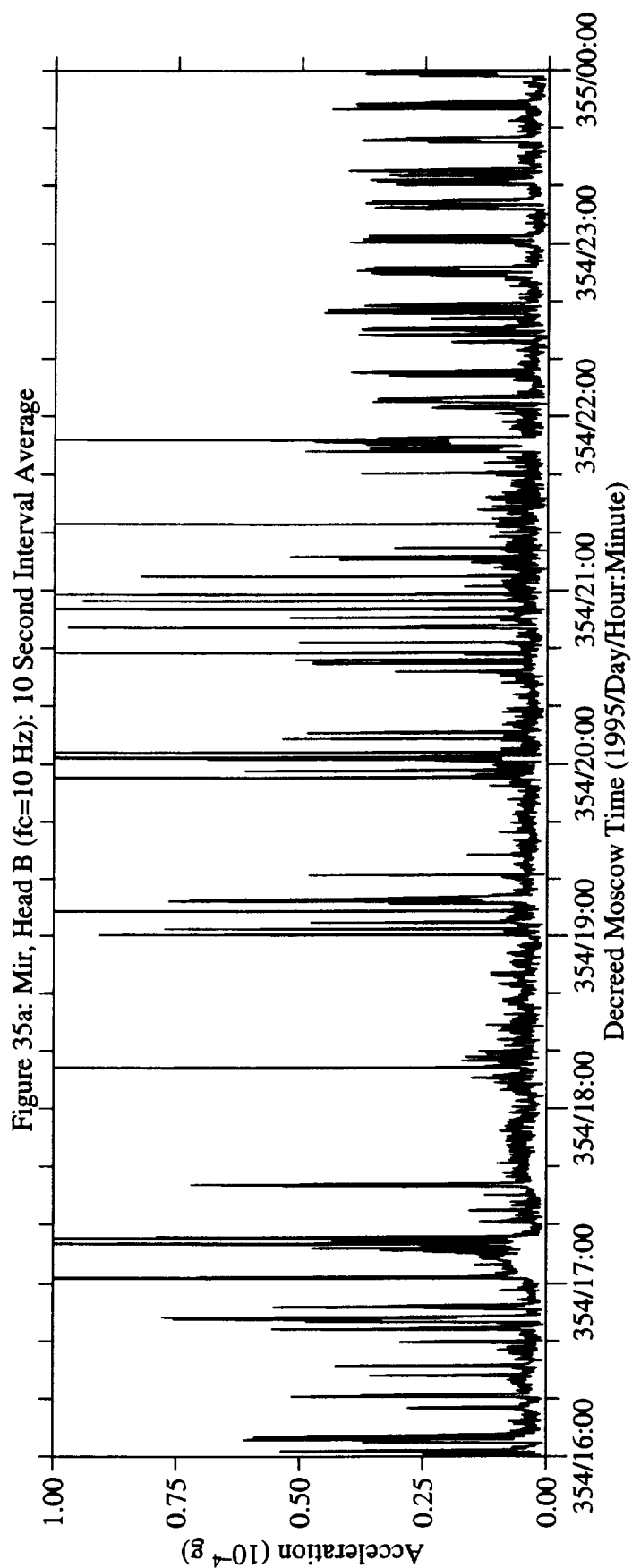


Figure 33b: Mir, Head B (fc=10 Hz): 10 Second Interval RMS









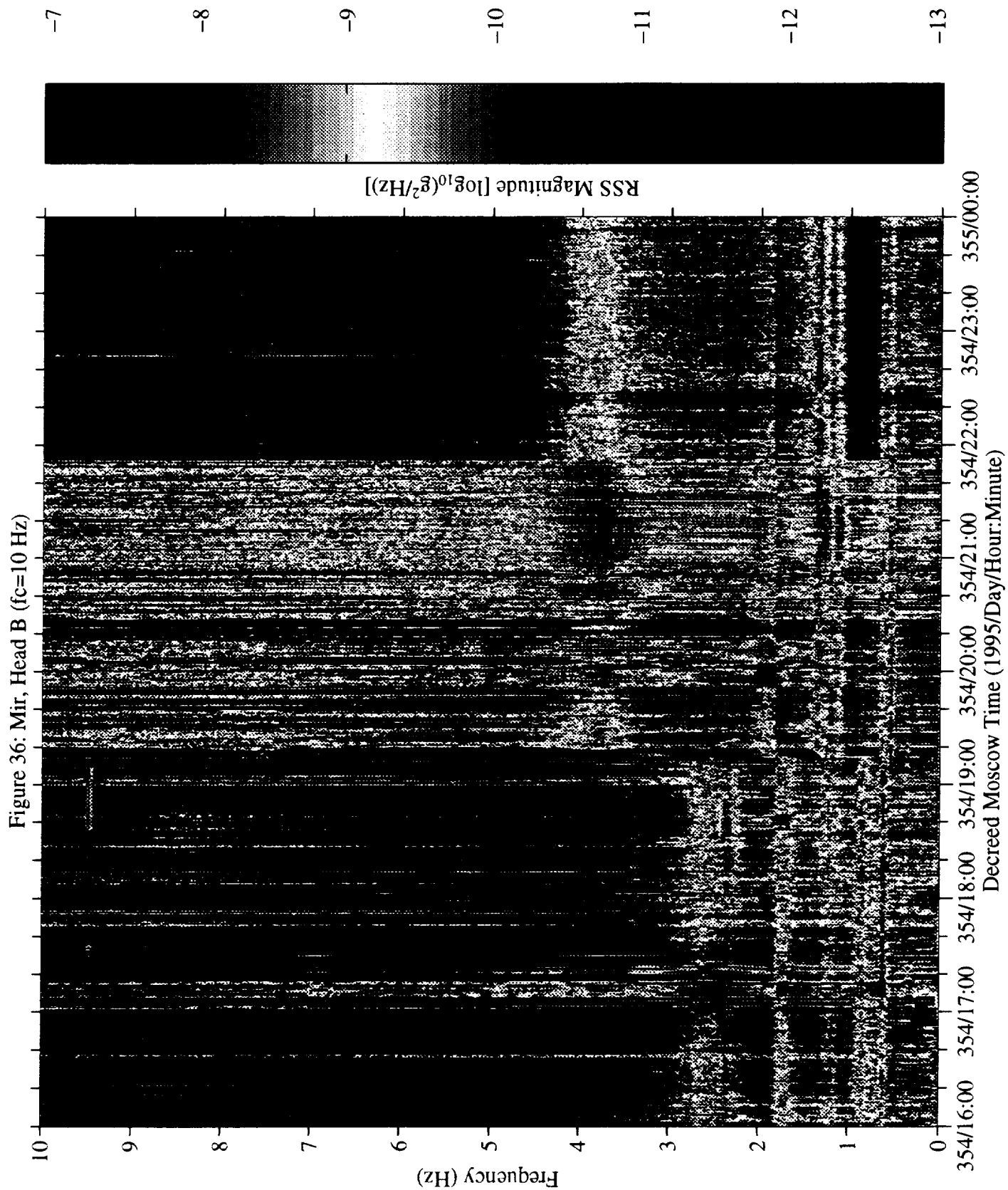


Figure 37a: Mir, Head B (fc=10 Hz): 10 Second Interval Average

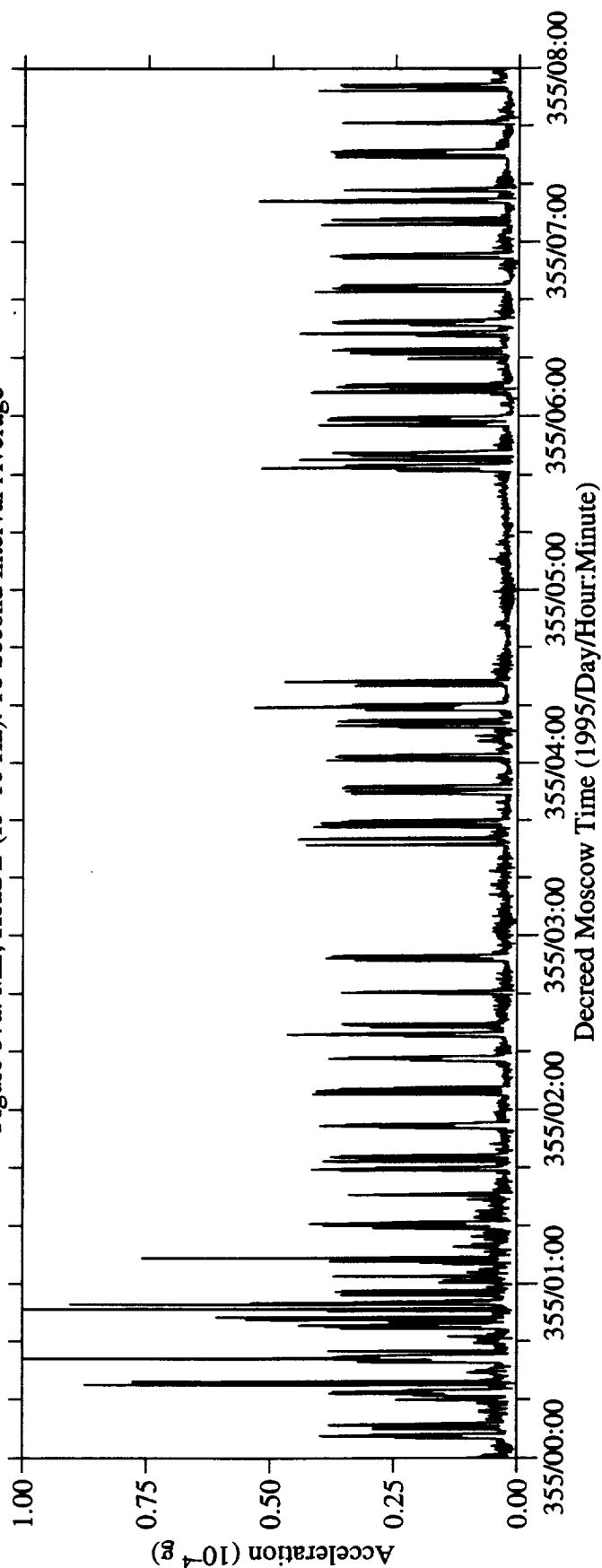
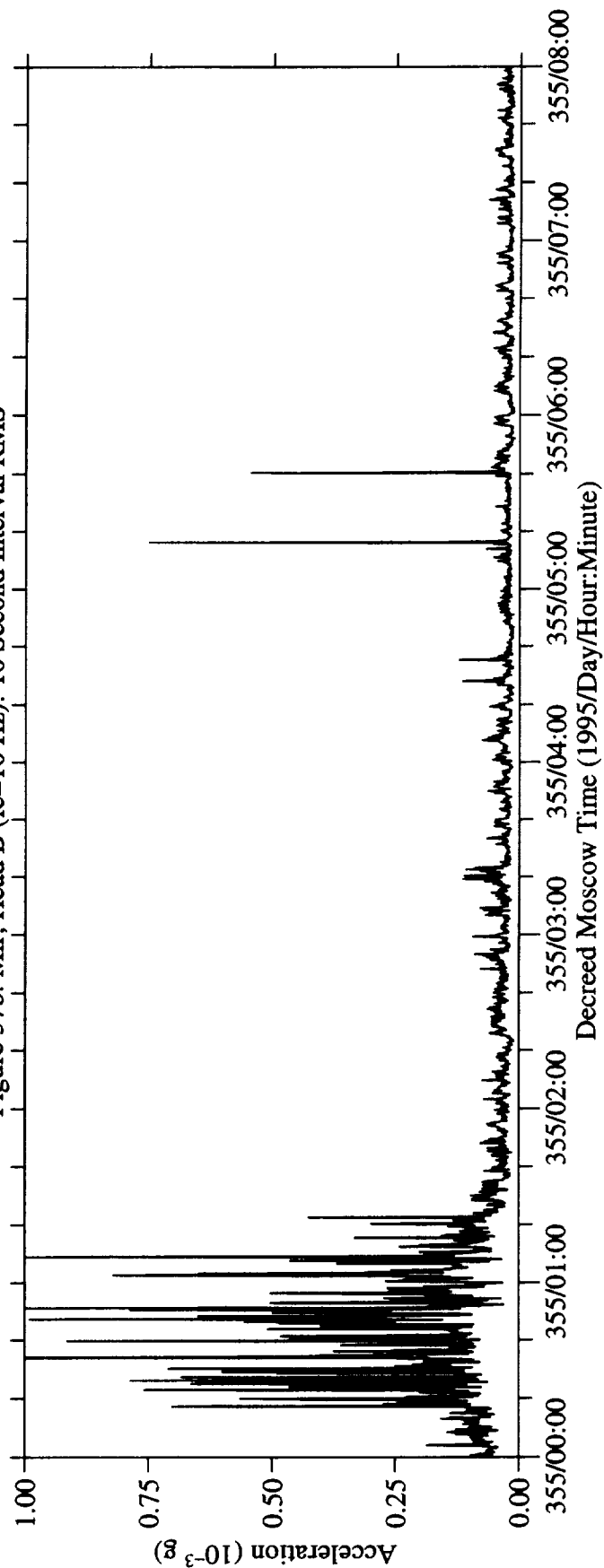
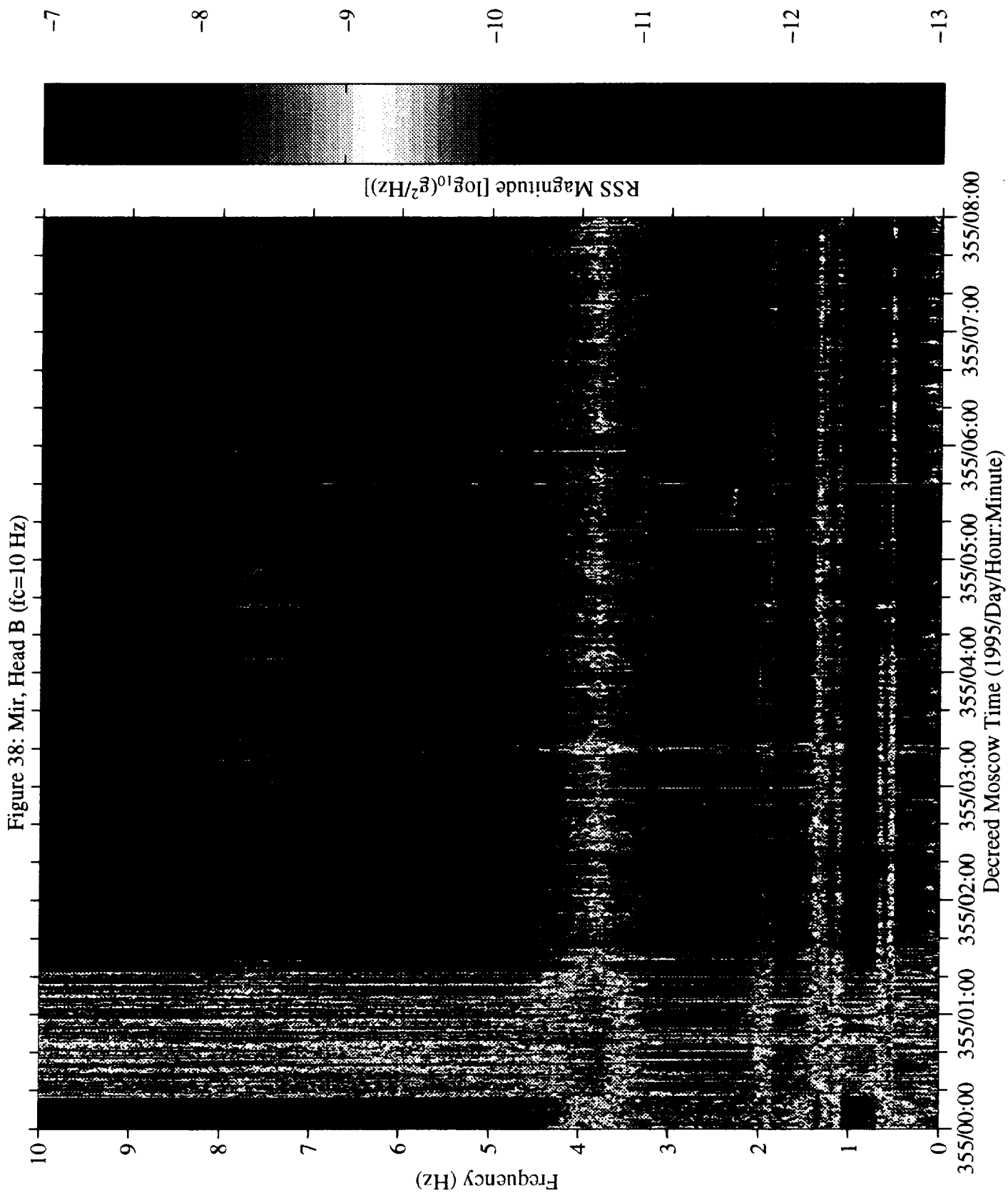
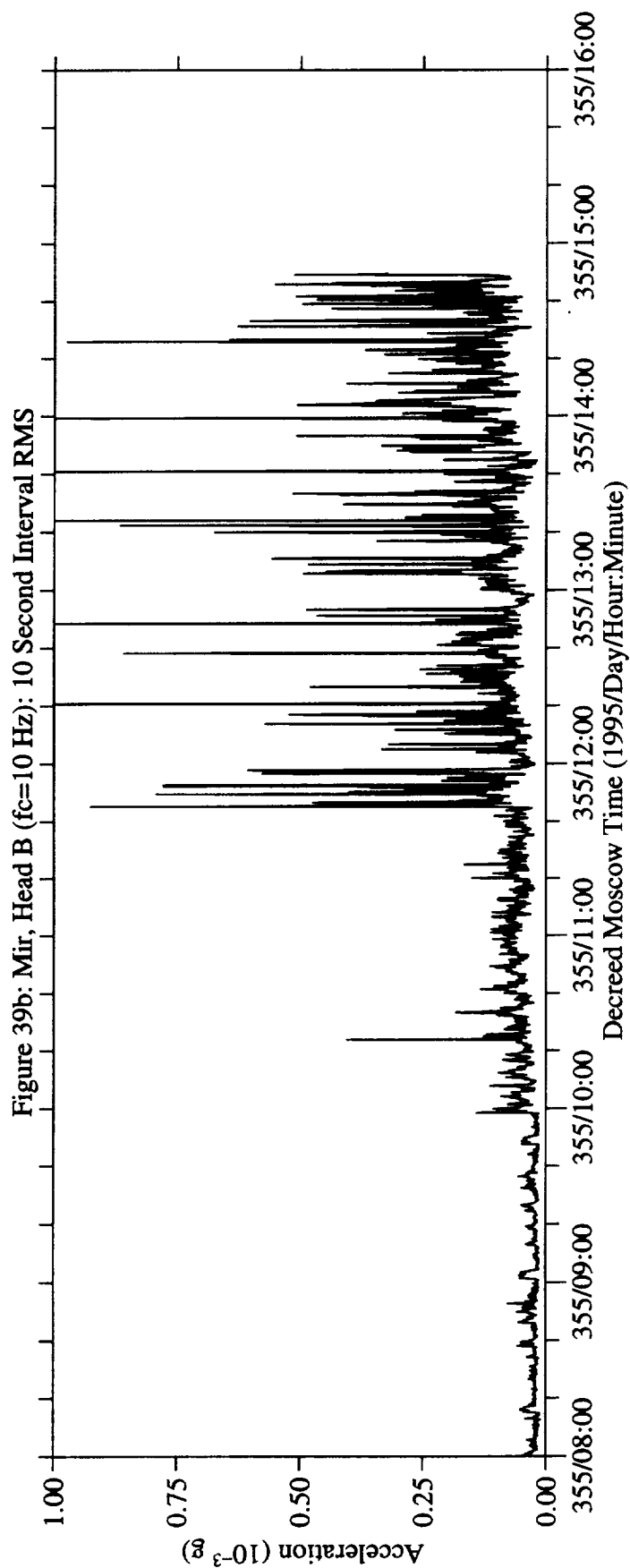
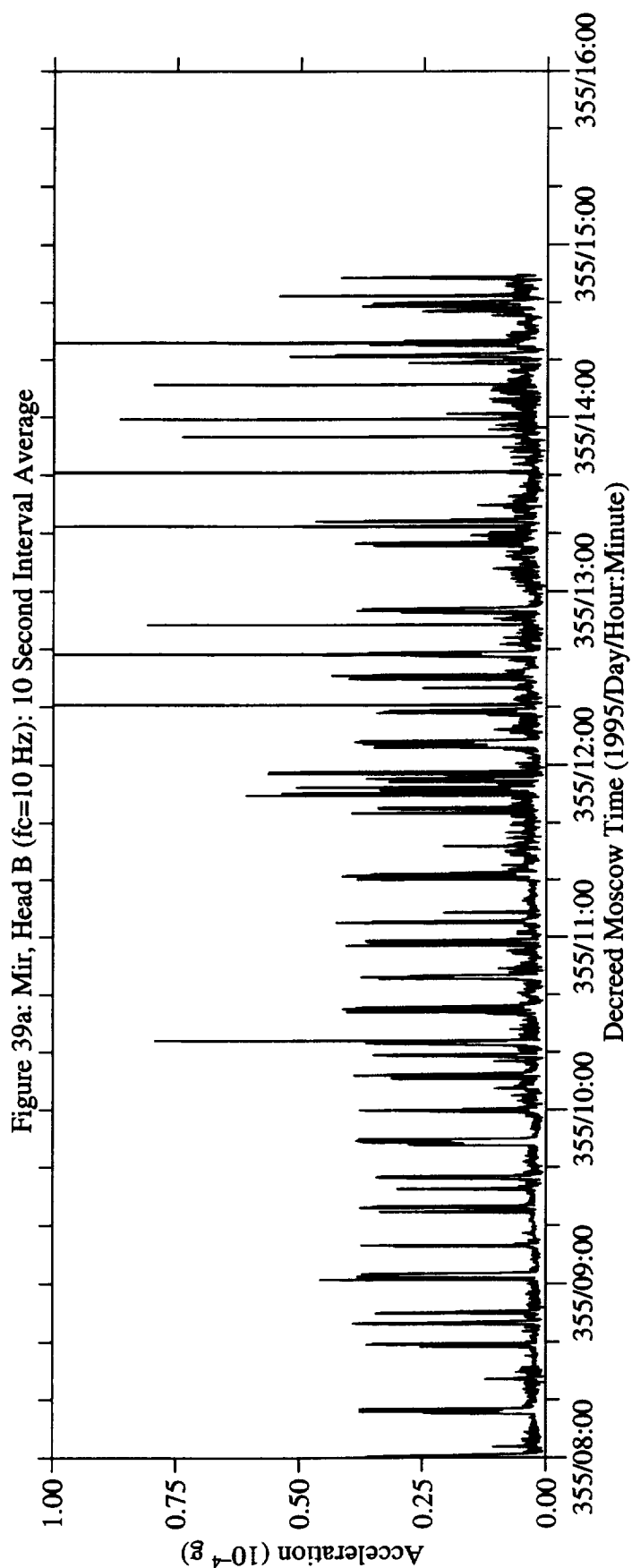
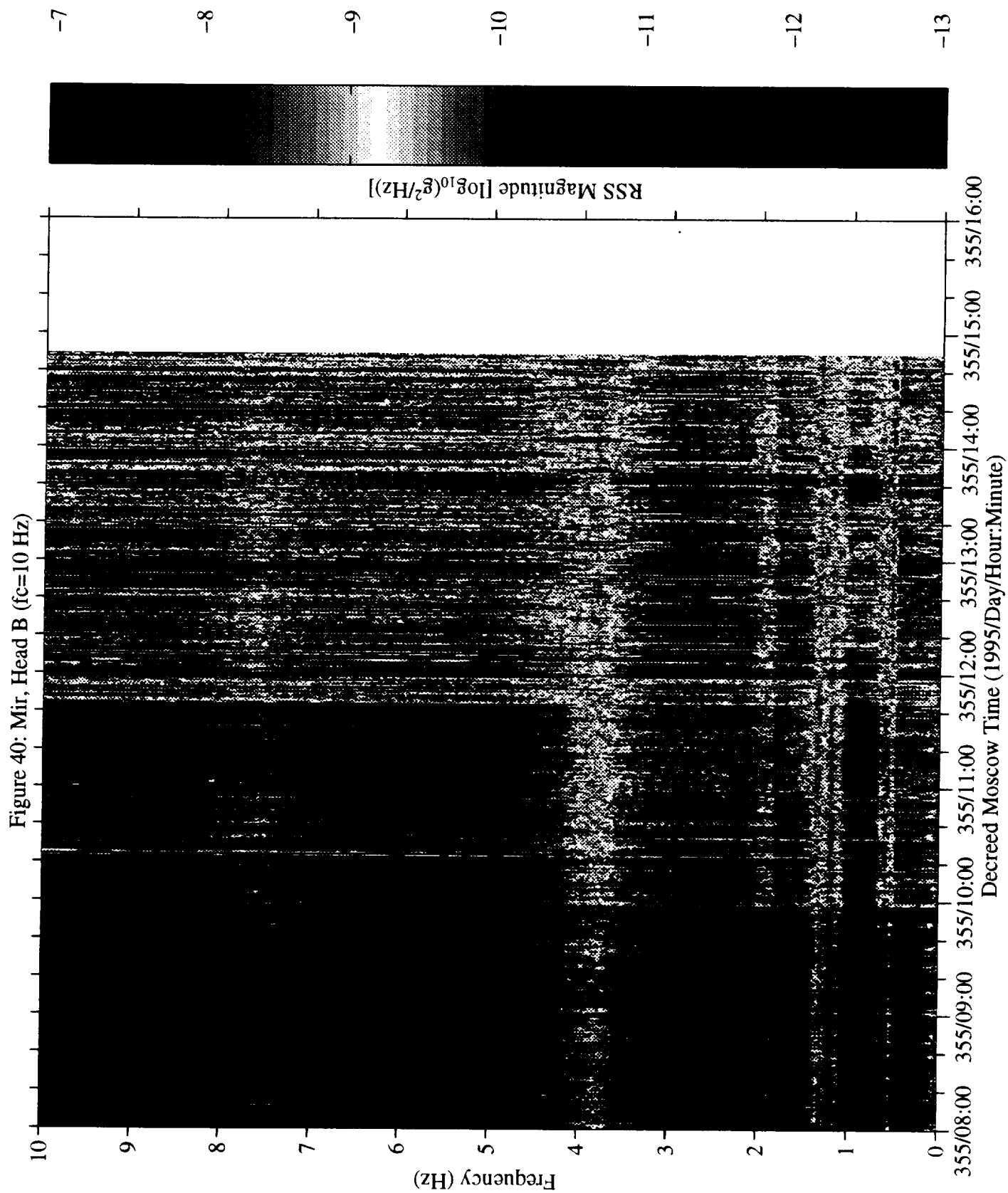


Figure 37b: Mir, Head B (fc=10 Hz): 10 Second Interval RMS



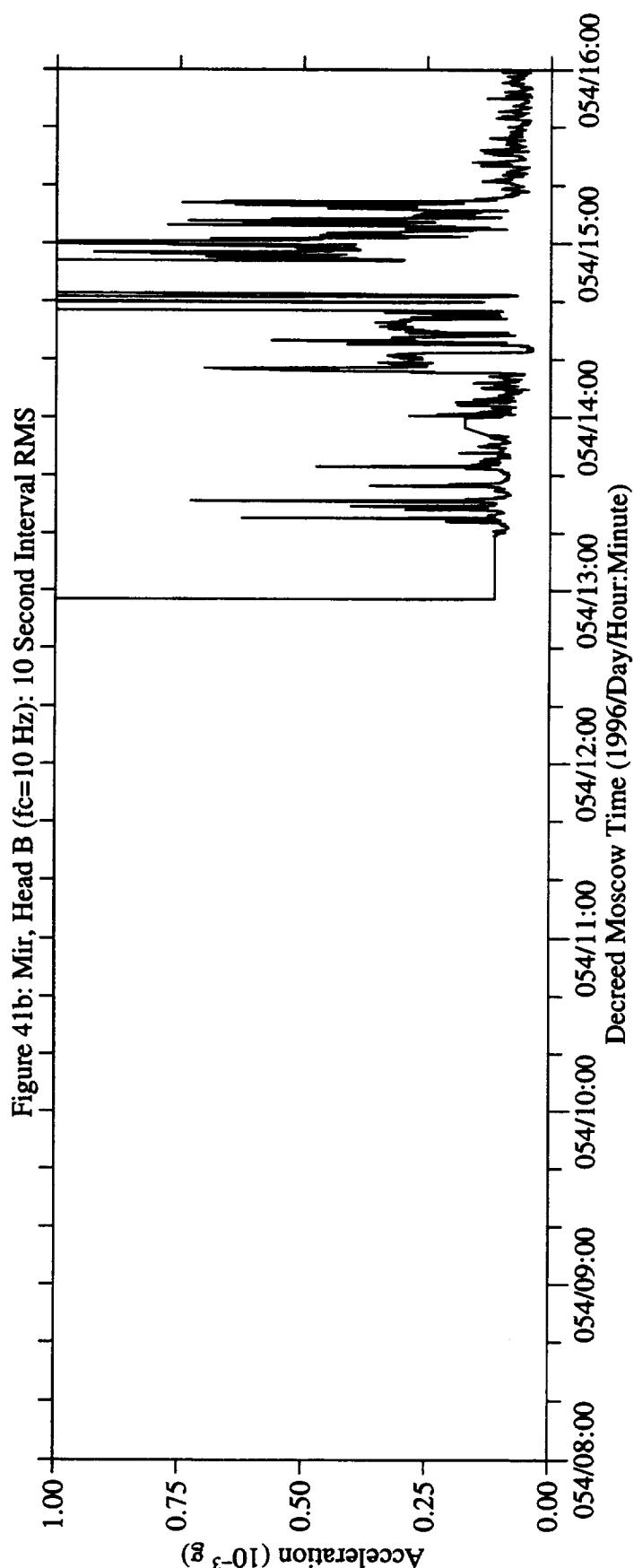
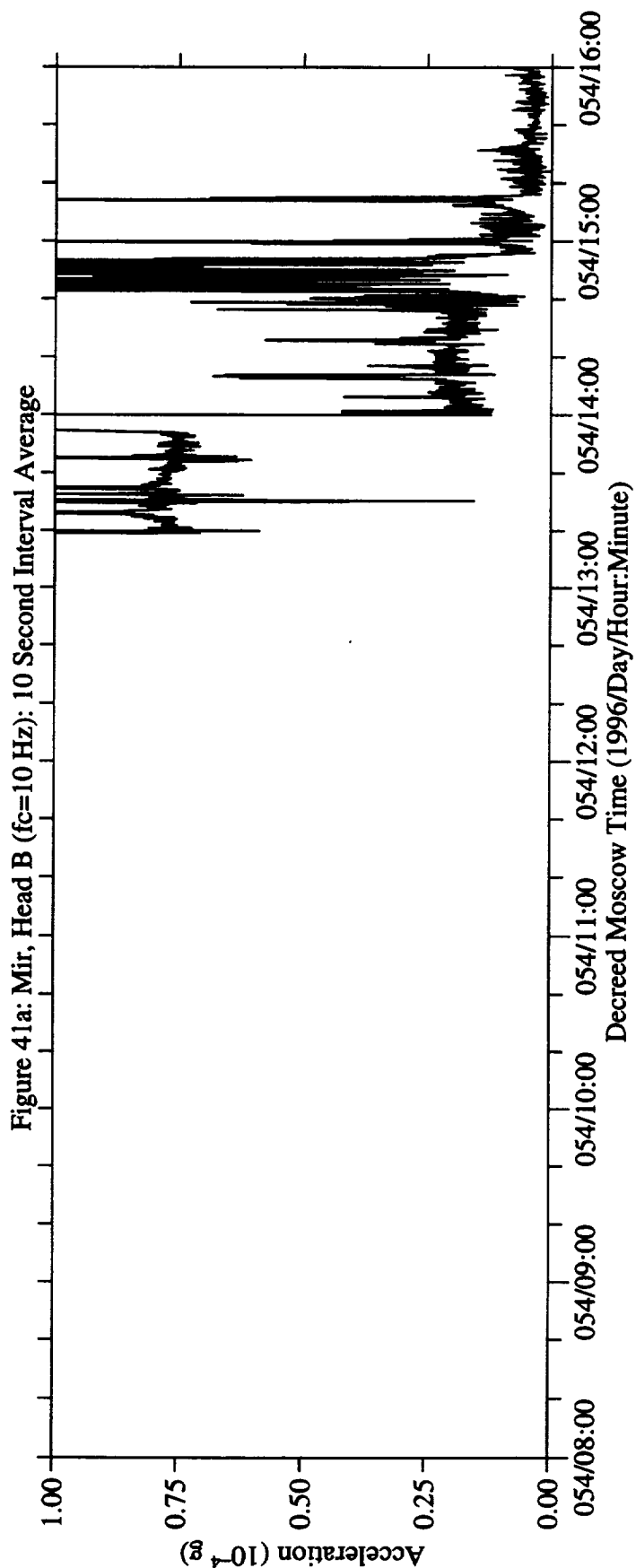




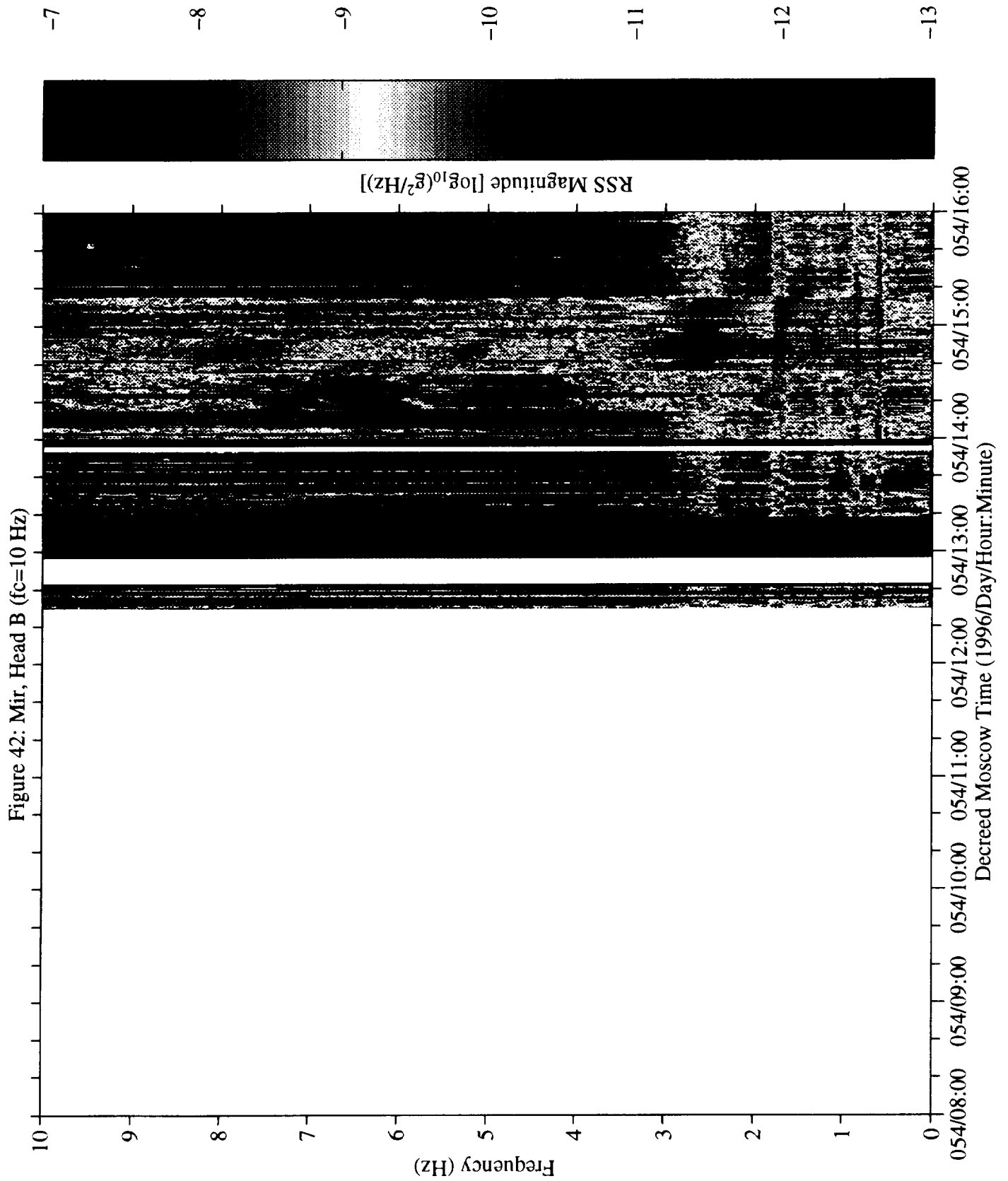


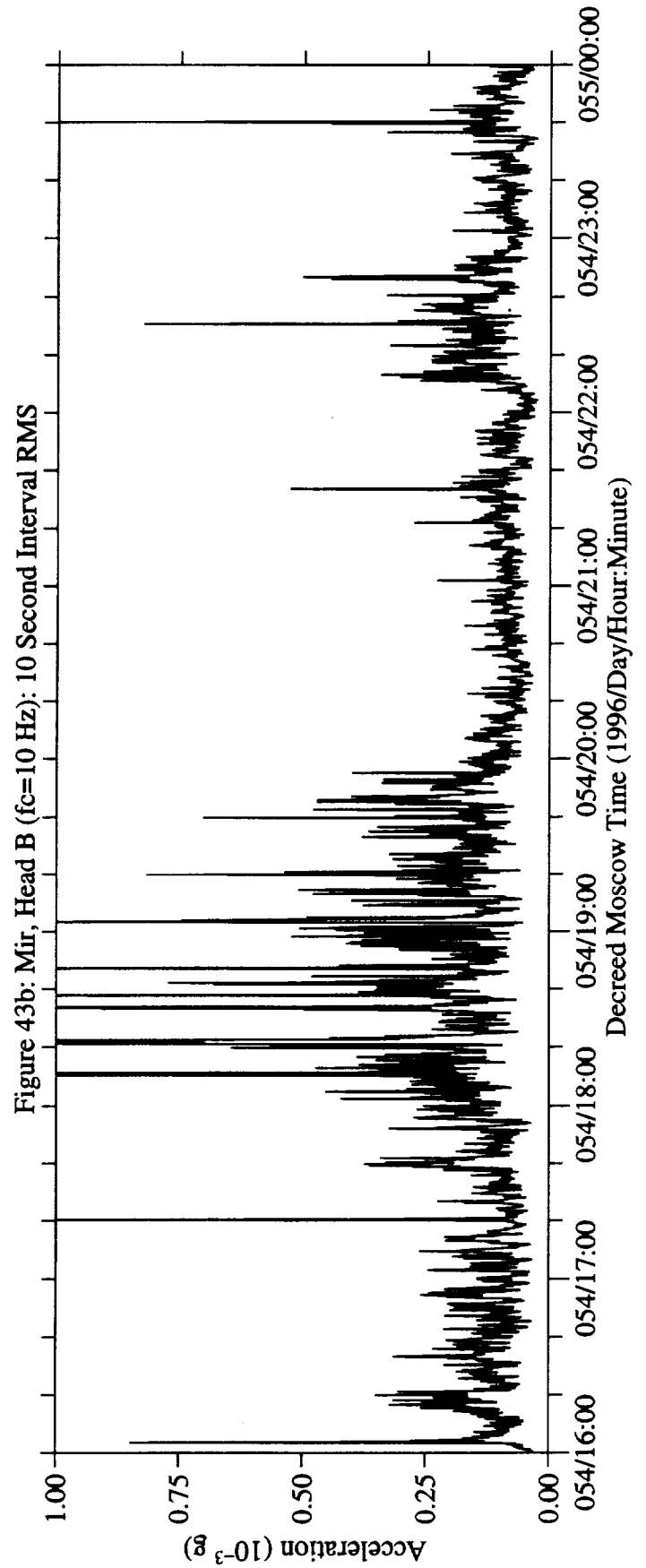
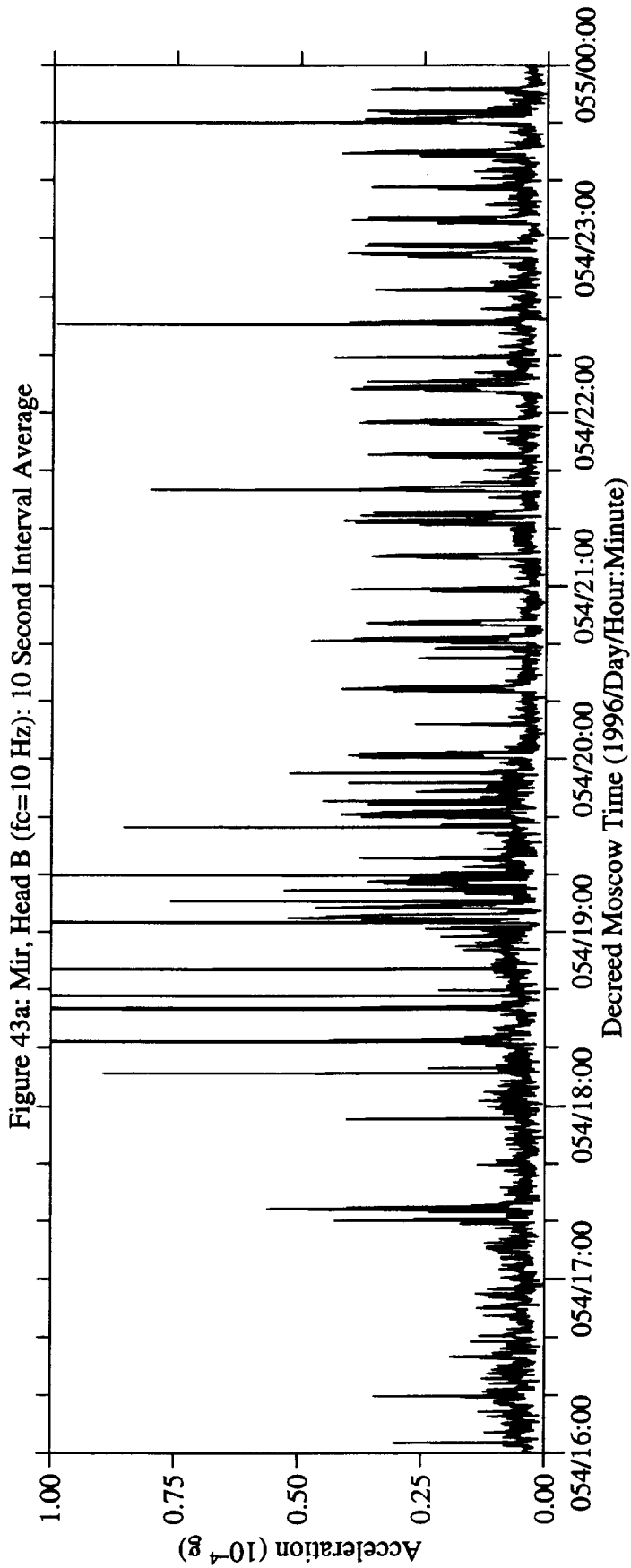
No data are available  
from 1995/355/16:00:00 to 1996/054/08:00:00

No data are available  
from 1995/355/16:00:00 to 1996/054/08:00:00









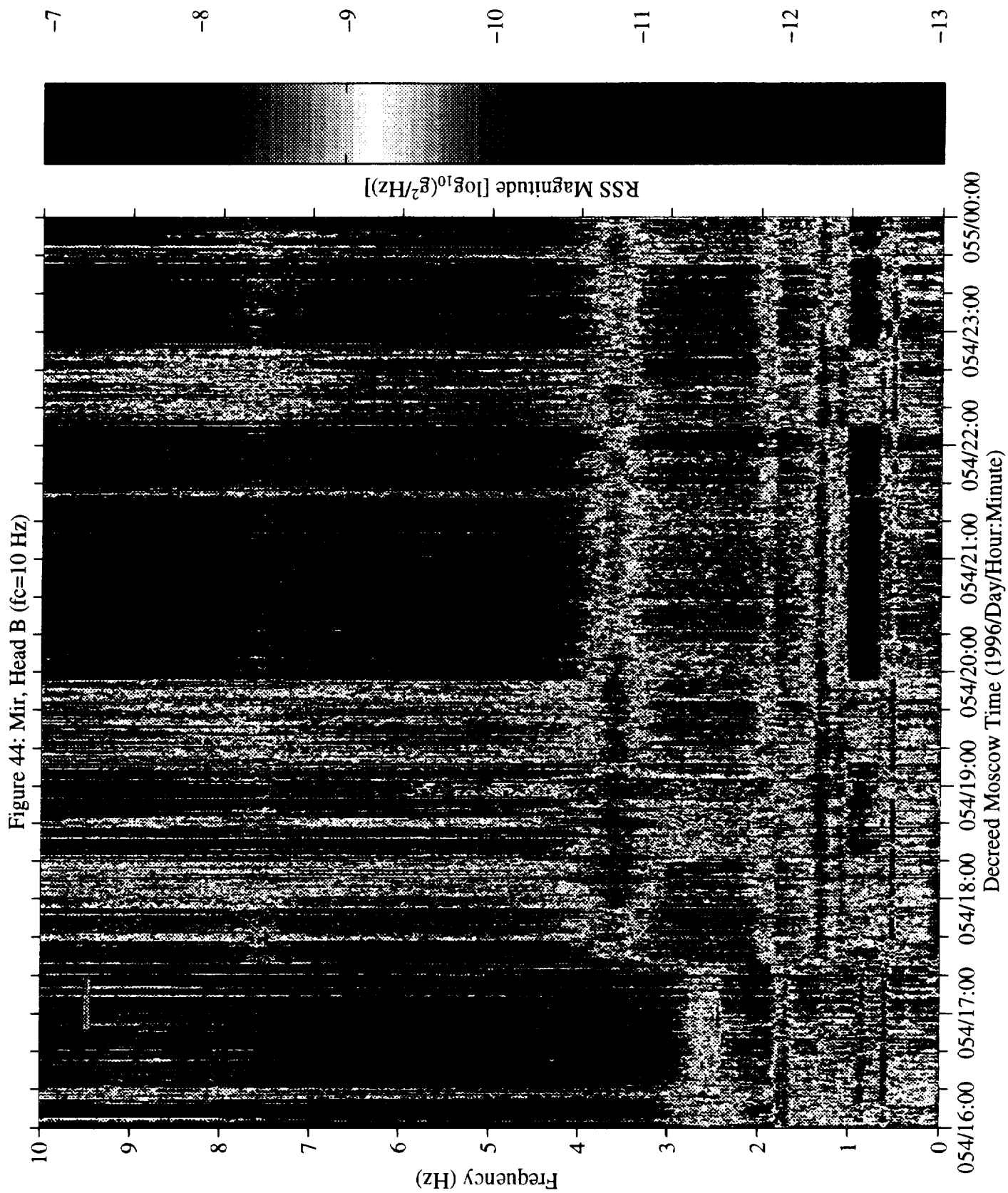


Figure 45a: Mir, Head B (fc=10 Hz): 10 Second Interval Average

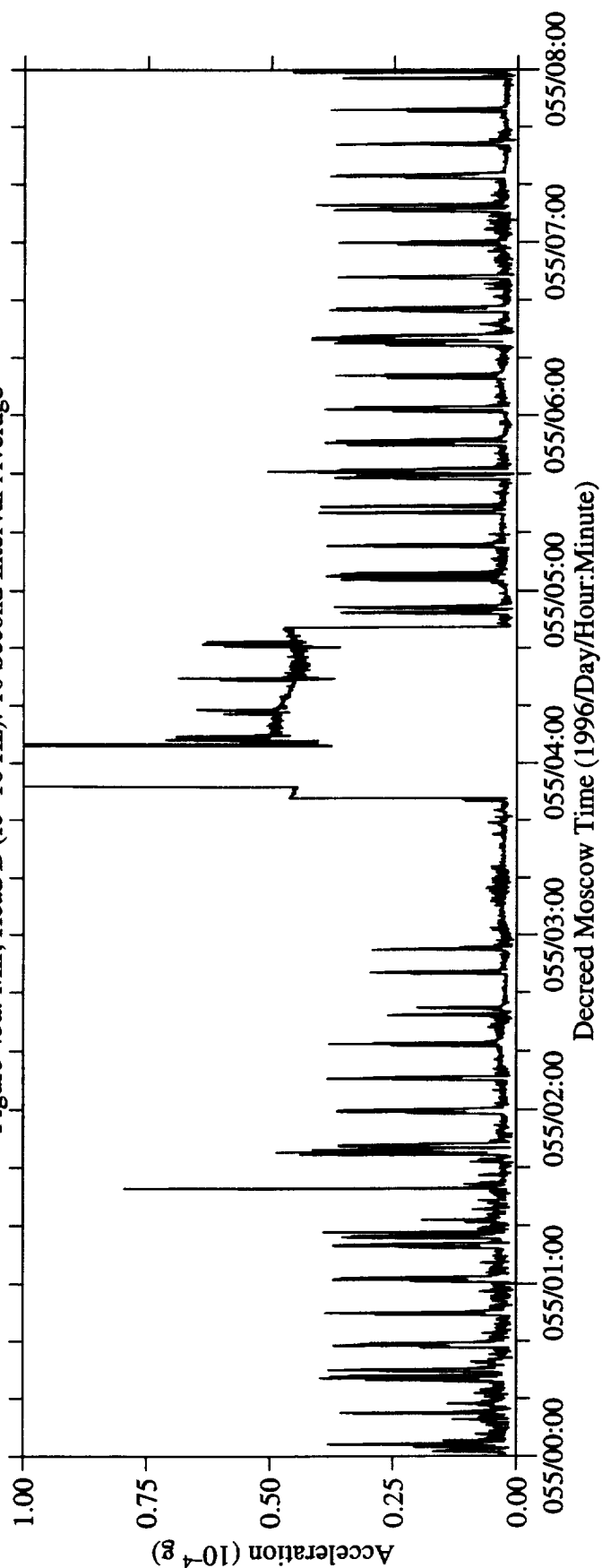
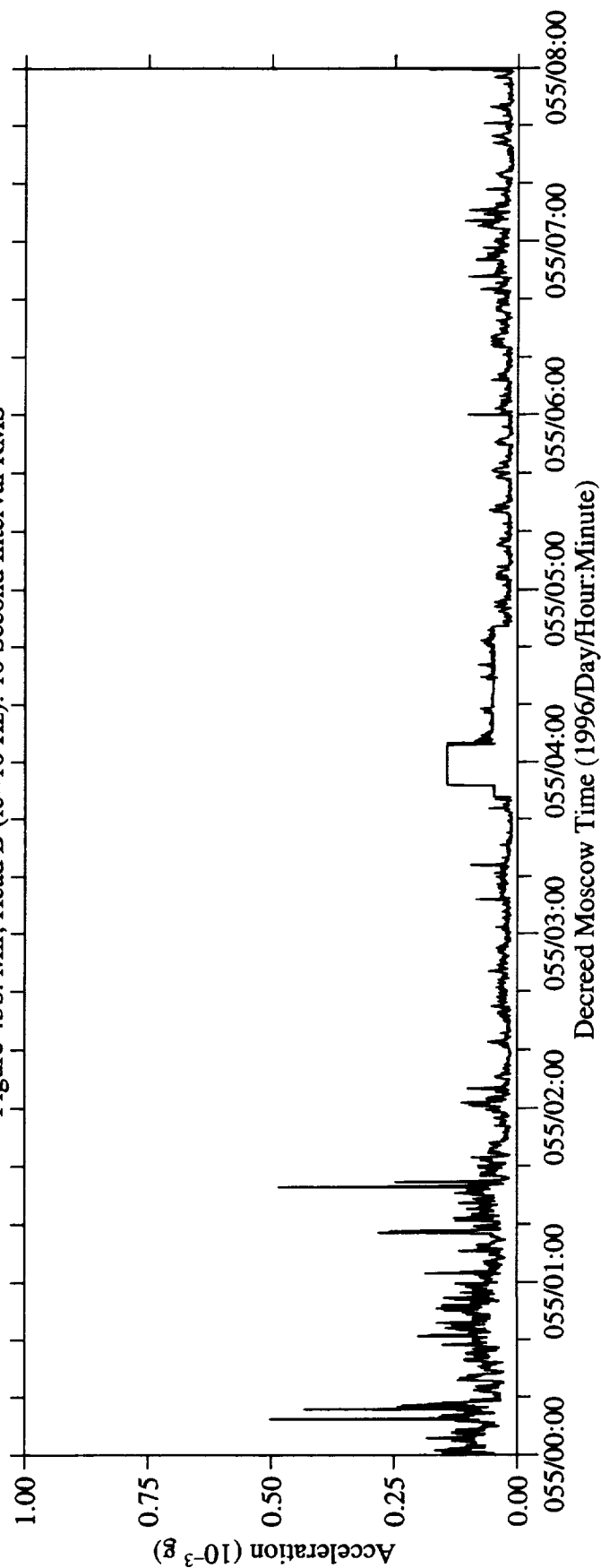
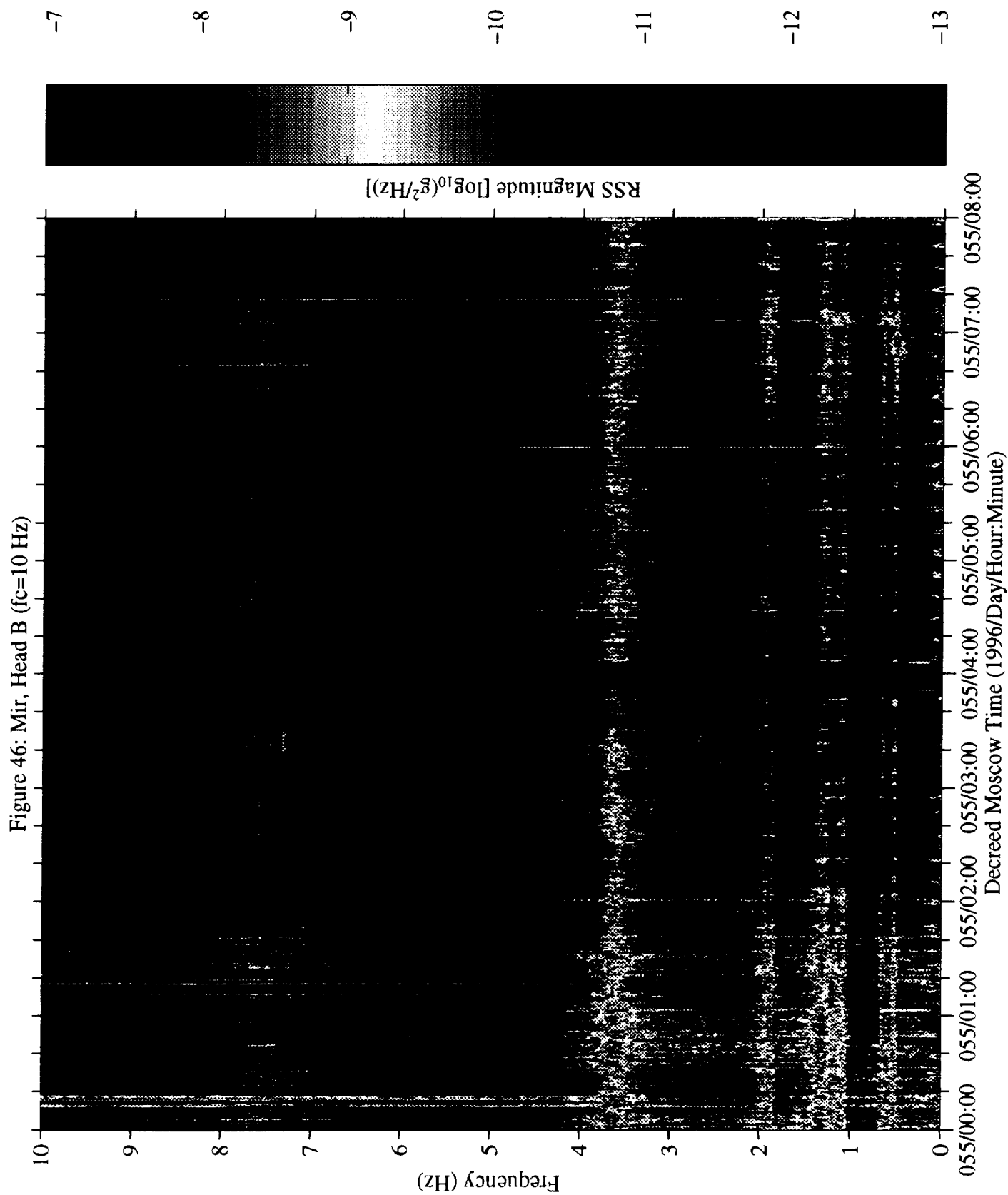
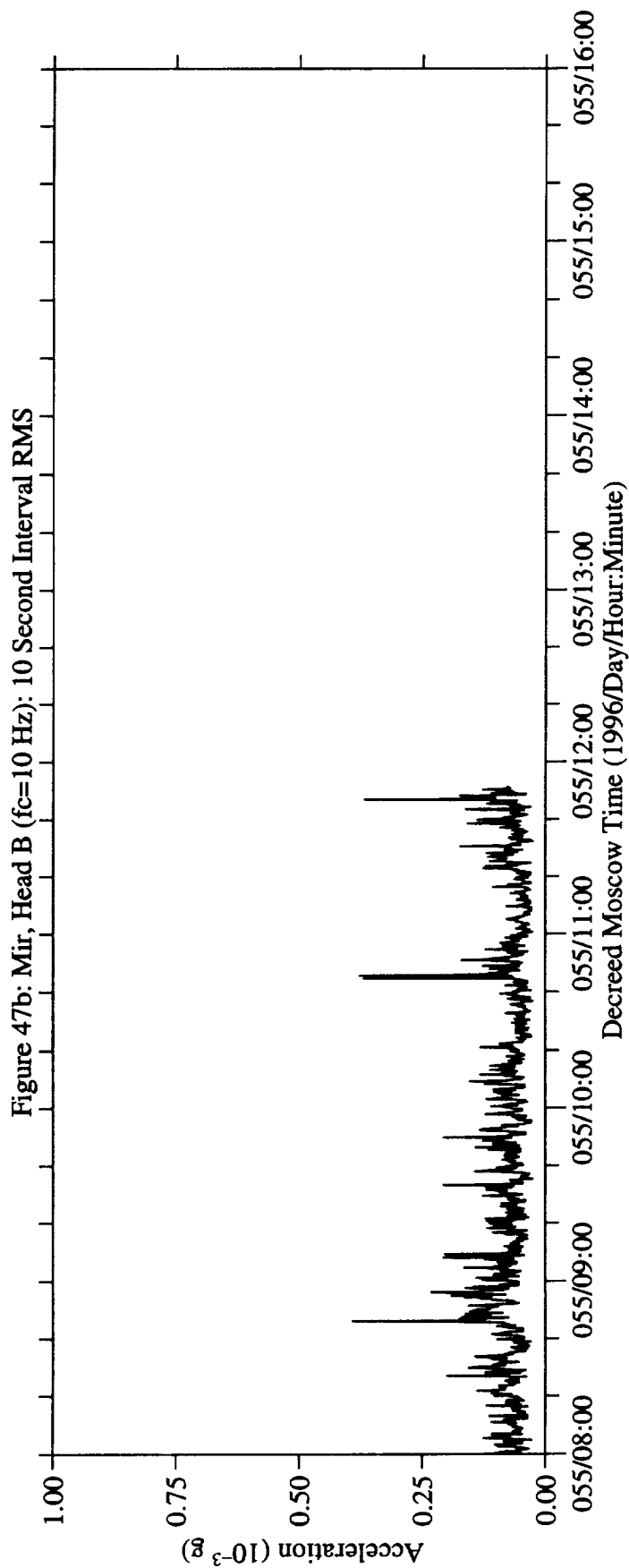
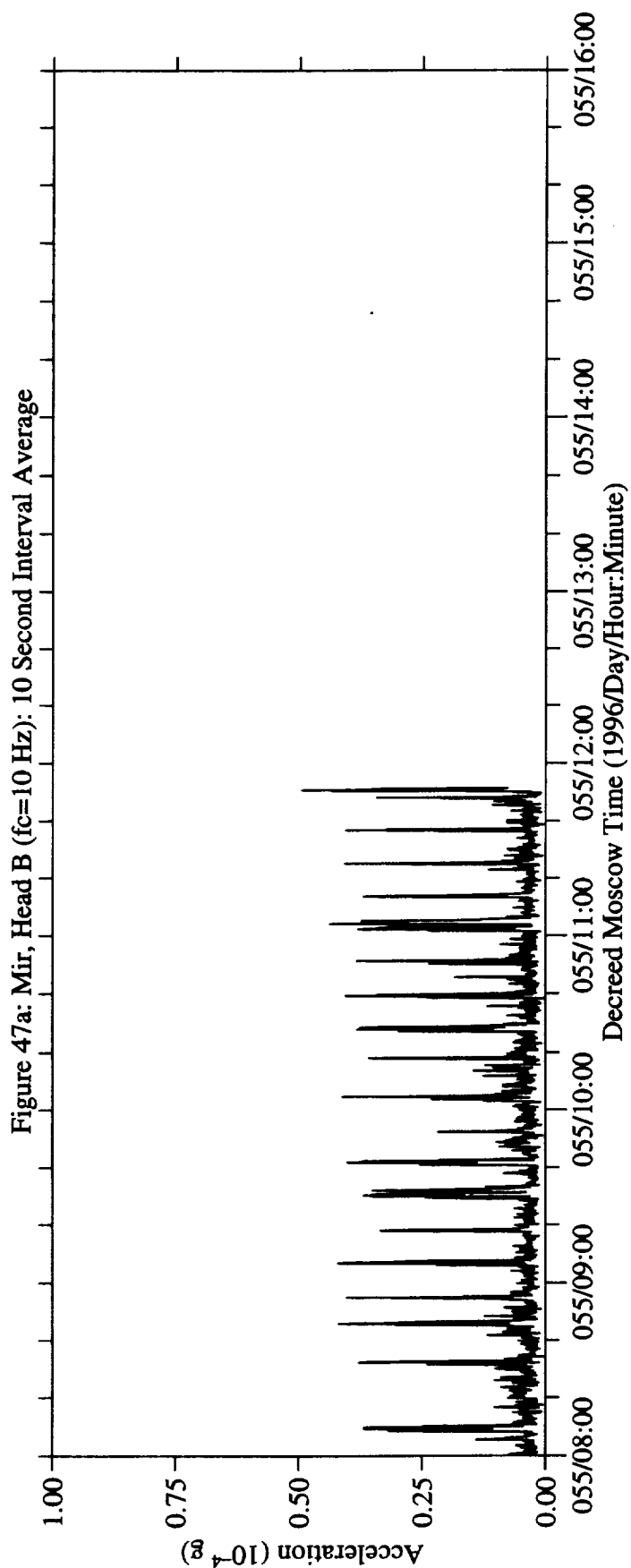
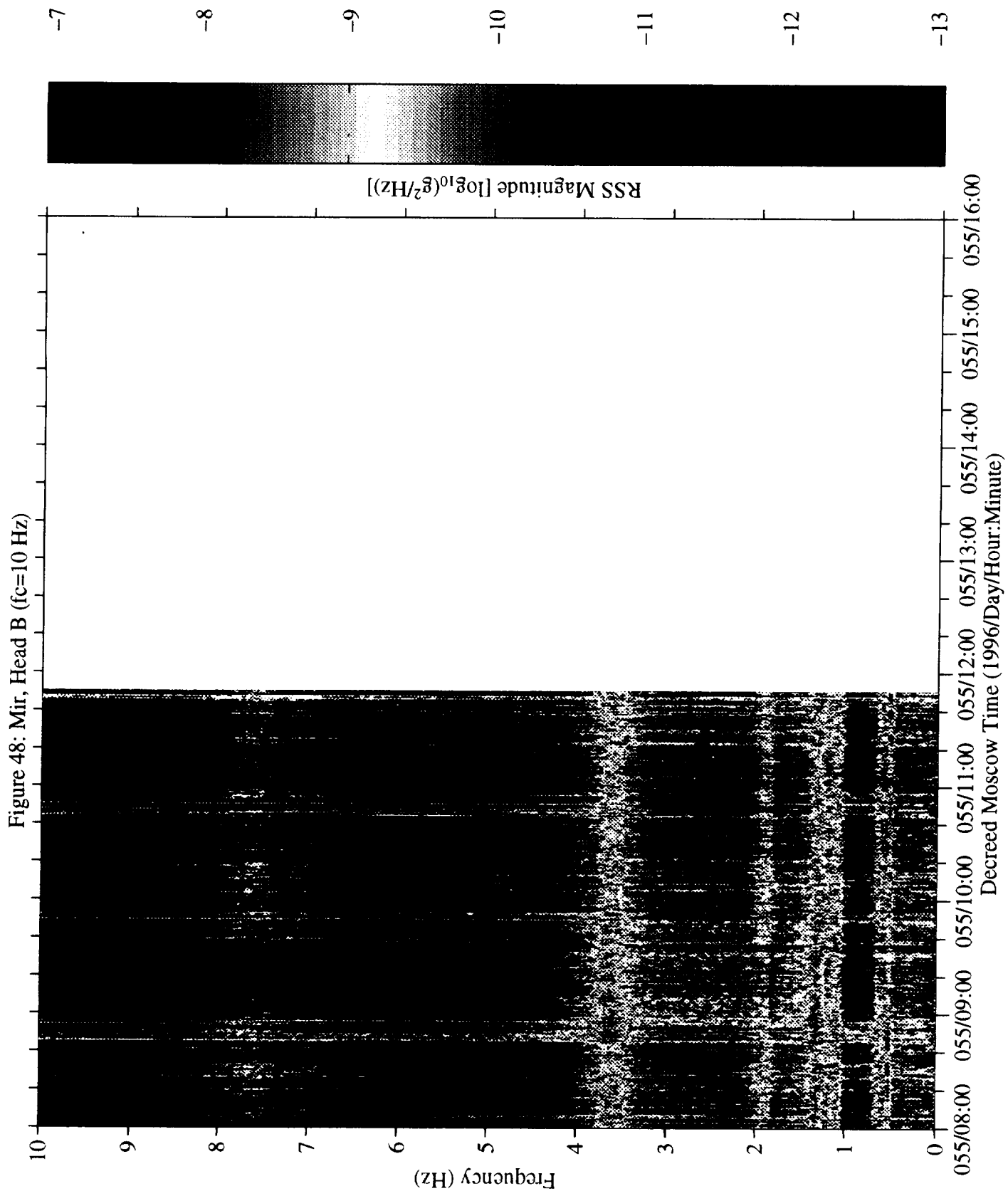


Figure 45b: Mir, Head B (fc=10 Hz): 10 Second Interval RMS













**Appendix D: User Comment Sheet**

We would like you to give us some feedback so that we may improve the Mission Summary Reports. Please answer the following questions and give us your comments.

1. Do the Mission Summary Reports fulfill your requirements for acceleration and mission information?  
 \_\_\_\_\_ Yes \_\_\_\_\_ No. If not why not?

Comments:

2. Is there additional information which you feel should be included in the Mission Summary Reports?  
 \_\_\_\_\_ Yes \_\_\_\_\_ No. If so what is it?

Comments:

3. Is there information in these reports which you feel is not necessary or useful?  
 \_\_\_\_\_ Yes \_\_\_\_\_ No. If so, what is it?

Comments:

4. Do you have internet access via: ( \_\_\_\_\_ )ftp ( \_\_\_\_\_ )WWW ( \_\_\_\_\_ )gopher ( \_\_\_\_\_ )other? Have you already accessed SAMS data or information electronically?

\_\_\_\_\_ Yes \_\_\_\_\_ No

Comments:

Completed by: Name: \_\_\_\_\_ Telephone \_\_\_\_\_

Address: \_\_\_\_\_ Facsimile \_\_\_\_\_

\_\_\_\_\_ E-mail addr \_\_\_\_\_

**Return this sheet to:**

**Duc Truong**

**NASA Lewis Research Center**

**21000 Brookpark Road MS 500-216**

**Cleveland, OH 44135**

**or**

**FAX to PIMS Project: 216-433-8660**

**e-mail to: pims@lerc.nasa.gov.**





| REPORT DOCUMENTATION PAGE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                             |                                                            | Form Approved<br>OMB No. 0704-0188                                      |                                                          |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|------------------------------------------------------------|-------------------------------------------------------------------------|----------------------------------------------------------|
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20603.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                             |                                                            |                                                                         |                                                          |
| 1. AGENCY USE ONLY (Leave blank)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                             | 2. REPORT DATE<br>April 1997                               |                                                                         | 3. REPORT TYPE AND DATES COVERED<br>Technical Memorandum |
| 4. TITLE AND SUBTITLE<br><br>SAMS Acceleration Measurements on Mir From November 1995 to March 1996                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                             |                                                            | 5. FUNDING NUMBERS<br><br>WU-963-60-0K                                  |                                                          |
| 6. AUTHOR(S)<br><br>Richard DeLombard                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                             |                                                            |                                                                         |                                                          |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><br>National Aeronautics and Space Administration<br>Lewis Research Center<br>Cleveland, Ohio 44135-3191                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                             |                                                            | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER<br><br>E-10698              |                                                          |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br><br>National Aeronautics and Space Administration<br>Washington, DC 20546-0001                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                             |                                                            | 10. SPONSORING/MONITORING<br>AGENCY REPORT NUMBER<br><br>NASA TM-107435 |                                                          |
| 11. SUPPLEMENTARY NOTES<br><br>Responsible person, Richard DeLombard, organization code 6727, (216) 433-5285.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                             |                                                            |                                                                         |                                                          |
| 12a. DISTRIBUTION/AVAILABILITY STATEMENT<br><br>Unclassified - Unlimited<br>Subject Categories 20, 35, and 18<br><br>This publication is available from the NASA Center for AeroSpace Information, (301) 621-0390.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                             |                                                            | 12b. DISTRIBUTION CODE                                                  |                                                          |
| 13. ABSTRACT (Maximum 200 words)<br><br>The NASA Microgravity Science and Applications Division (MSAD) sponsors science experiments on a variety of microgravity carriers, including Orbiter missions and Russia's Mir space station. The MSAD sponsors the Space Acceleration Measurement System (SAMS) at the NASA Lewis Research Center (LeRC) to support these science experiments by providing acceleration measurements to characterize the microgravity environment to which the experiments were exposed. The LeRC Principal Investigator Microgravity Services (PIMS) project supports principal investigators of microgravity science experiments as they evaluate the effects of varying acceleration levels on their experiments. In 1994, a SAMS unit was installed on the Mir space station. In a manner similar to Orbiter mission support, the SAMS unit supports science experiments from the U.S. and Russia by measuring the microgravity environment during experiment operations. Previous reports have summarized the SAMS data acquired during the period from September 1994 to November 1995. During the time period from November 1995 to March 1996, the primary SAMS-supported experiment was a Protein Crystal Growth (PCG) experiment. SAMS data were obtained during the PCG operations on Mir in accordance with the requirements specified by the PCG Principal Investigator. Also included in this data are mission events of interest, such as the undocking of STS-74 from Mir (November 1995) and the docking of Atlantis (STS-76) to Mir in March 1996. This report presents an overview of the SAMS data recorded in the interval from November 1995 to March 1996. |                                                             |                                                            |                                                                         |                                                          |
| 14. SUBJECT TERMS<br><br>Microgravity environment; Mir; SAMS; Acceleration measurements                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                             |                                                            | 15. NUMBER OF PAGES<br>149                                              |                                                          |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                             |                                                            | 16. PRICE CODE<br>A07                                                   |                                                          |
| 17. SECURITY CLASSIFICATION<br>OF REPORT<br>Unclassified                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 18. SECURITY CLASSIFICATION<br>OF THIS PAGE<br>Unclassified | 19. SECURITY CLASSIFICATION<br>OF ABSTRACT<br>Unclassified | 20. LIMITATION OF ABSTRACT                                              |                                                          |